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A COMPARISON OF PROPOSED AIR EXPEDITIONARY FORCE PACKAGES USING THE THUNDER CAMPAIGN SIMULATION PROGRAM

THESIS

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THESIS

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Brian M. Godfrey

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Abstract

There are currently only two force packages under consideration for Air Expeditionary Force (AEF) deployment: the *Eagle* package and the *Falcon* package. This thesis examines these and three other force packages for operational feasibility.

The comparisons made between the five packages were based on five operational measures and two which describe the logistics involved with deploying each package. The operational measures and one logistics measure are obtained from the THUNDER simulation software package. The other logistics measure, amount of short-tons of cargo required to support each package, was obtained from the Logistics Plans office at HQ ACC.

The principal contribution is a methodology for modeling and analyzing AEF packages using THUNDER and statistical tools. A key result (based on two notional scenarios) was that adding additional F-16 aircraft to the single MDS (all F-16) package had a negligible impact on many of the measures.

Furthermore, the single MDS package recorded the most air-to-air kills and enemy ground targets destroyed. These are counterintuitive, because two of the other packages contained equal numbers of F-15Cs and F-15Es. Note that these results should be verified by using an actual theater scenario for THUNDER.

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I. Introduction

Background

In August of 1997, the commander of the Air Combat Command (ACC), General Richard Hawley, dedicated the Air Expeditionary Force (AEF) Battlelab at Mountain Home Air Force Base, Idaho. General Hawley stated that, "…the mission of the battlelab is to figure out ways we can make ourselves lighter and more agile. This will help get forces deployed to where they are needed on short notice with less airlift than we've needed in the past and without as big a requirement for support upon arrival." (Mattson, 1997:1).

Brigadier General William R. Looney III, Commandant of the Armed Forces Staff College, wrote an article entitled, *The Air Expeditionary Force: Taking the Air Force into the Twenty-First Century* which appeared in the Winter 1996 issue of the Airpower Journal. In it, he describes an AEF as a package consisting of 30 aircraft: twelve aircraft serving in an air-to-air role, twelve air-to-ground (strike) aircraft, and six aircraft to perform a suppression of enemy air defenses (SEAD) mission (Looney, 1996: 6). At an AEF conference in the Spring of 1998, the number of SEAD aircraft was increased to twelve, bringing the size of the entire package to 36 aircraft. Also at the conference, the idea of including heavy bombers from the CONUS in the package was proposed. Taking off from their home stations, B-1s and/or B-52s could rendezvous with the strike package and increase the air-to-ground capability of the AEF (Hoxie, 1998).

A package such as the one described could be expected to generate between 40 and 60 sorties per day. As of the publication date of General Looney's article, it is estimated that approximately 1000 personnel would be required to support an AEF. This figure would increase to 1,175 if tanker support is included. Early estimations of airlift required placed a demand of fifty to sixty C-141 equivalents (Looney, 1996: 7-8).

When planning for an AEF deployment, trade-offs must be made between operational effectiveness and logistics requirements. The more diverse and capable an air package is, the more it requires in terms of logistics support. Conversely, a force mix which does not take advantage of its full range of combat capability is sacrificing operational output, but experiences logistics benefits.

The concept of an AEF is different from the common deployment of a squadron in that an AEF is meant to be short-term, and that it will eliminate the current 90- to 120-day rotations overseas. By the year 2000, it is hoped that the idea will have evolved to the point where two of the projected ten AEFs will sit on what is similar to alert status which rotates every 90 days. This cycle will repeat approximately every 15 months. If a tasking comes down for a squadron to deploy, members plan for a seven-day operation (Katzaman, 98:1).

During this time, the unit provides a quick, sustained, initial strike capability, designed to halt (or at least delay) the advance of an enemy. While the AEF is conducting the campaign, other units back in the states are mobilizing. These units will bring other weapon systems to the theater to provide a diverse package of airpower (Meserve, 1998).

It is expected that the concept of an AEF will take advantage of the ease of mobility associated with a short-term deployment, and be able to conduct effective operations. Any operational short-comings will be eliminated when the main force arrives and begins to conduct operations on or about the seventh day. At that time, if deemed necessary by warplanners, force packages taking full advantage of the flexibility of current air power will conduct operations. In this manner, the AEF will experience the logistics benefits of a "light" deployment and conduct operations in the short-term, and a main force will experience the operational benefits of a "heavy" deployment.

The Intent of This Research

The purpose of this study is to compare the operational output and required logistics support for the following four air packages under consideration by the AEF Battlelab:

Package 1:	12 ea F-15C (Air-to-air) 12 ea F-15E (Air-to-ground) 12 ea Block 50 F-16 (SEAD)
Package 2:	12 ea Block 30 F-16 (Air-to-air) 12 ea F-15E (Air-to-ground) 12 ea Block 50 F-16 (SEAD)
Package 3:	12 ea F-15C (Air-to-air) 12 ea Block 40 F-16 (Air-to-ground) 12 ea Block 50 F-16 (SEAD)
Package 4:	12 ea Block 30 F-16 (Air-to-air) 12 ea Block 40 F-16 (Air-to-ground) 12 ea Block 50 F-16 (SEAD)

Package four is of particular interest because it is the only force mix consisting of a single mission design series (MDS), or type of aircraft. It is expected that this package will be

the lightest to deploy in terms of short-tons of support equipment required. This is because much of the equipment sent to support a given squadron in the package could be cross-utilized by other squadrons participating in the AEF.

The all F-16 (single MDS) package is included in the force mixes under consideration because of that aircraft's ability of perform all missions required of an AEF. There is no package consisting solely of F-15s because that aircraft does not perform the SEAD mission. Although it can carry more ordnance than an F-16 performing the same mission (therefore requiring fewer sorties to attack the same number of targets), this one shortcoming eliminates it from consideration when examining the feasibility of a single MDS AEF.

If it turns out that package four is the lightest package in terms of support equipment required, the next step would be to determine how many aircraft (and how many short-tons of support equipment) would be required to provide the same measures of combat output as the heavier deployments. This is a logical step, since the F-16 carries less ordnance than an F-15 performing the same mission. The expected benefit comes from the lighter deployment, but effectiveness is sacrificed. The true measure of the benefit (and aim of this thesis) is to determine if a larger number of F-16s can compare with the other force packages in terms of operational output. It is for this reason that a fifth package will be included in the analysis:

Package 5: 18 ea Block 30 F-16 (Air-to-air)
18 ea Block 40 F-16 (Air-to-ground)
18 ea Block 50 F-16 (SEAD)

Package five consists of eighteen aircraft in each mission (squadron) because that number is the next incremental increase for force packages, as described by current planning documents. This package serves as a method of performing a sensitivity analysis to the results of both the operational output and support equipment requirements. If package four provides the least combat output of the four packages previously defined (but still experiences the logistics benefits of a single MDS deployment), package five is an attempt to determine if more aircraft in a single MDS deployment can approach the combat output of a dual MDS AEF with fewer aircraft.

This is an interesting prospect in light of the intuitive idea that this package would also experience the logistics benefits (if any) of a single MDS deployment. Although this force mix will most likely require more support than package four, it deserves consideration in this analysis due to its expected increase in combat output.

THUNDER Campaign Analysis Package

This thesis uses the THUNDER theater simulation software package as a means to compare the combat effectiveness of each package. The first version of THUNDER used by the Air Force was TAC THUNDER in 1986. The version used in this study, 6.4, was introduced in 1996. The current version is the result of more than a dozen upgrades to the original and considers more elements of a campaign to make the program more versatile. Improvements incorporated into the prior version to create 6.4 include a more active flight path generation algorithm to avoid surface to air (SAM) sites; improved identification, surveillance, and reconnaissance (ISR) functions; utilization of satellites in the performance of (ISR) missions; and more interaction between supporting carrier task

forces and other units in the battlespace (THUNDER Analyst Manual [TAM], Version 6.4, Vol 1: 1996: 21).

THUNDER is in wide use by the United States Air Force analysis community as well as the following military and civilian agencies:

> National Defense War Gaming and Simulation Center,
> United Kingdom Ministry of Defence Directorate of Science (Air),
> Royal Air Force - Cranwell Department of Air Warfare,
> Boeing Military Airplane Division,
> Rockwell International,
> French Ministry of Defence Bureau de Prospective et de Recherche Operationelle,
> Northrop-Grumman Advanced Technology and Development Center, and
> Institute for Defense Analysis (TAM, Version 6.4,Vol 1; 25: 1996).

Input for THUNDER comes from over 80 different input data files, describing (among other things) type and number of aircraft in the theater, weather bands, command and control measures, air defenses, ground targets, and probability of kill (PK) data of munitions preprogrammed into the software. The THUNDER package includes three preprogrammed scenarios entitled *Datasmall*, *MacAir*, and *ME*. These allow the novice user to become familiar with the simulation package (TAM, Version 6.5, Vol 3; 1996: 2).

Input data for the preprogrammed scenarios consist of notional, unclassified information describing the probable enemy threat, expected allied presence, and order of battle in an area. *Datasmall* and *MacAir* describe a European theater, whereas *ME* describes a Middle East scenario. The information preprogrammed into these data files are best estimates for each parameter. They are the most reliable unclassified data available (TAM, Version 6.5, Vol 3; 1996: 2).

An additional database, *Storm*, is included in the version maintained by AFIT and is based on a Middle East scenario with data from Operation DESERT STORM. Data for past AFIT theses have been based on either the *ME* or *Storm* scenarios. Upon becoming familiar with THUNDER using the preprogrammed scenarios, the user can modify appropriate input data files to reflect the situation under study. In this study, data programmed into THUNDER were the proposed AEF packages in the *Storm* scenario. Output from the five air packages were compared to get an idea of how each performed in relation to the other four in terms of combat effectiveness.

Research Questions

1. *What is the ranking of the five AEF packages in terms of combat effectiveness and support required?*

It is expected that package one consisting of F-15Cs in the air-to-air role, F-15Es serving in air-to-ground, and Block 50 F-16s performing the SEAD function will have the highest combat output in terms of enemy ground targets destroyed, enemy aircraft destroyed, etc. The second and third packages are expected to be similar to each other in terms of effectiveness. Finally, the forth package, consisting solely of F-16s, would likely be the least combat effective.

Constraints on airlift make the logistics involved with deploying an AEF a primary issue. Not only is volume of equipment a concern, but also the timeline required to meet the "lean, light, and lethal" goals of an AEF (Parsons, 1998). In terms of support equipment required, the package consisting of two squadrons of the larger, twin-engine F-15 (package one) is expected to require more support equipment and spare parts than

any other package. Packages two and three are expected to be somewhat lighter and similar to each other due to the fact that both packages consist of two squadrons of F-16s and one squadron of F-15s. Finally, the lightest package is expected to be package four, the single MDS package due to cross-utilization possibilities of spare parts and support equipment.

2. Would increasing the number of aircraft in the lightest package increase that package's combat output?

Increasing the number of aircraft in any package should increase that package's output. If the original package is light to begin with, the increase in its support requirement for additional aircraft may be acceptable. Package five attempts to answer this question. If the support requirements of these additional aircraft is acceptable, it may be beneficial to accept the increased support to achieve a greater combat output.

3. Is the relative ranking of combat effectiveness of each air package constant throughout different threat scenarios?

Although a given package my be less effective than the others in the preprogrammed *Storm* scenario, an attempt will be made to find a scenario which reorders the ranking of the packages. An alternate scenario will be programmed in which different mixes of enemy aircraft and surface threats exist in an attempt to reorder the effectiveness rating of the packages under study.

Organization

The Literature Review reveals past research into areas similar to these research questions. As mentioned before, several theses have been written based on data obtained

from THUNDER. These are discussed in the review, as well as other works addressing support requirements from different angles. General Looney's article explaining the AEF concept has already been mentioned. The literature review discusses other articles relevant to logistics support and combat effectiveness of AEFs.

Chapter III explains the methodology employed to answer the research questions. The manipulation of appropriate THUNDER input data files is discussed and justification for each modification is provided. Default values and the baseline scenario in THUNDER are explained in the chapter, as well as measures of effectiveness (MOEs) used as bases of comparison between the five air packages.

Analysis of the MOEs from THUNDER is provided in Chapter IV. Statistical tools are used to rank the air packages in terms of combat output and support requirements.

Chapter V consists of conclusions and recommendations, and contains a summary of the findings and answers the research questions provided earlier.

Limitations

It was mentioned earlier that the *Storm* scenario is a notional database. This characteristic will affect the output. However, the methodology and analysis are appropriate regardless of classification. This limitation will be addressed as an avenue for further research.

Another limitation of this research is that although data describing short-ton requirements are given, the amount of support personnel required for each package is not included as a measure for comparison. Personnel requirements are not examined because

of the time needed to perform a proper analysis of available logistics data. Therefore, logistics requirements are only based on estimates for the amount of short-tons required for each package.

Finally, only those aircraft weapons configurations included in the original *Storm* database (as they appear in the *typeac.dat* data file) were used. (*typeac.dat* and other files are discussed in the Methodology section.) This was due to the classification constraint. No classified weapons configurations are included.

II. Literature Review

This chapter reviews the literature available on the topic the AEF and the THUNDER simulation package. Previously accomplished theses employing THUNDER are of particular interest due to the fact that they provide insight of the utility of THUNDER beyond its obvious use as a war planning tool. These studies also assist the novice THUNDER user in how to use the software to get the desired information. Appropriate input data file manipulation is essential to effective use of the package. This comes in large part from knowing the information that each data file contains, as well as how to interpret the data contained in the files.

Once the analyst becomes familiar with data in the files, they can then begin to make minor manipulations to the files with the aim of discovering how each seemingly insignificant piece of data impacts the entire set of output metrics. From this type of experimentation, the analyst will begin to understand how THUNDER reads the input data files and interprets that data to create the scenario and conduct the war. Understanding of THUNDER's operation is a great facilitator in effectively using the software.

Prior AEF Research

It is expected that the most combat-capable package would be package one as described earlier. But the effectiveness of an AEF consisting solely of F-16s is also of interest in this study. The idea of a single MDS AEF is fairly new to offensive strategy. A review of the DTIC database, the EBSCO search software, and previous theses revealed no prior research in this area, although there are several journal articles and

research papers on the concept of an AEF. These provided a basis for background research and introduced the idea of an AEF.

The previously mentioned article by Brigadier General Looney provides excellent insight into the notion of an AEF. Although the concept at the time of publication was still in its infancy (its appearance in the *Journal* preceded the AEF Battlelab dedication by almost one year), its principles are in large part still true. The only significant difference between the scenario General Looney described and the current design is the addition of six SEAD (Block 50 F-16) aircraft (Hoxie: 1998).

John A. Tirpac, Senior Editor of Air Force Magazine, contributed an article to the June 1998 issue in which he explains future roles for the B-1. In the article, Colonel Glenn Spears, commander of the 28th Operations Group at Ellsworth AFB, explains the preferred role of the B-1 as part of a package. The package is described as consisting of "F-15s for fighter cap (combat air patrol), F-16CJs (Block 50 F-16s) with HARM missiles for Suppression of Enemy Air Defenses, some F-16s as bomb droppers, and some F-15Es for precision weapons drop…"(Tirpac, 1998: 30). This package described by Colonel Spears resembles the packages under investigation in the study.

First Lieutenant Tam Vo's *Exploratory Analysis of the Deployment Feasibility of United States Air Force Air Expeditionary Forces* thesis describes the Navy's carrier battle group and the Marine Expeditionary Force, concepts on which the AEF is based. She also illustrates the sequence of events on the 48-hour timeline which describes the deployment schedule of an AEF. The timeline begins with the warning order and ends with bombs on target (Vo, 1997: 43). Lt Vo also states the difficulty past AEFs had in

meeting this goal. The idea of a single MDS AEF is born from the challenges associated with deploying such a diverse package as an AEF would require. Lessons learned from the first four AEF deployments are also given by Lt Vo as a guide to future planning.

In addition to articles and past theses, there have been several briefings presented by personnel from the AEF Battlelab, the Air Force Logistics Management Agency (AFLMA), and the RAND Corporation concerning AEFs. Captain Robert Vaughn of AFLMA presented a briefing to Lieutenant General Jumper, Air Force Director of Air Operations (AF/XO), and Lieutenant General Halin, Air Force Director for Installations and Logistics (AF/IL), in July of 1997 describing the lessons learned from the first three AEFs. Two major areas of concern he addresses are predeployment planning and political-military relations. The difficulties associated with predeployment planning were of particular concern due to the fact that, according to Captain Vaughn, lessons learned from AEFs I and II were not used in the preparations for AEF III (Vaughn, 1997).

Political-military relations come into play when considering the locations of the first three AEFs. AEF I operated out of Shaikh Isa, Bahrain; AEF II from Azraq, Jordan; and AEF III from Doha, Qatar. Relations between the host country and visiting military will always be a concern when operating from locations such as these. Someone unfamiliar with customs of the host country can unknowingly jeopardize the success of not only the current mission but future operations as well (Vaughn, 1997).

Captain Vaughn concludes by reiterating the fact that the AEF concept as practiced in AEFs I-III is sound. He attributes most of the problems encountered during AEF III to poor planning and not using lessons learned from AEFs I and II. He also

voices a concern that there is no standardized metric to measure AEF deployment efficiency (Vaughn, 1997).

Lieutenant Colonel Tony Dronkers from the Air Staff proposes metrics to measure various characteristics of interest concerning AEFs. Of primary concern is *response time*. This is a measure of how quickly air assets can arrive in theater. Response time differs from *time to effectiveness* in that the latter describes the time it takes for operations to begin once in theater. The number of pallet positions is widely accepted now as the standard used to describe how much equipment is used to support the initial arrival of a unit at the beginning of particular deployment (footprint). Demand pull is used to describe the amount of equipment (expressed in terms of pallets per day) needed to sustain a deployment (logistics pipeline) (Dronkers, 1997).

Lt Col Dronkers also explains the concept of regional contingency centers (RCCs). These are staging areas from which AEFs could be conducted in the future. There are currently four centers selected, each operating on a 1500-2000 nautical mile radius. The one in the Western Hemisphere would operate out of Roosevelt Roads and serve the southeastern portion of North America and northwestern quarter of South America. There is one centered in Western Europe at Moron, Spain and could cover all of Europe and the northwestern third of the African Continent. Southwestern and South-central Asia would be covered by an AEF staging from Diego Garcia. AEFs operating in Eastern and Southeast Asia would deploy to Guam (Dronkers, 1997).

The geographic location of each of these areas is such that they would put an AEF within striking distance of areas of potential hostilities. Further, Moron, Diego Garcia,

and Guam are all areas from which heavy bombers have operated in the past and could easily serve as staging bases for B-1s and B-52s serving in an AEF. An AEF operating from Roosevelt Roads would be augmented with B-52s from Barksdale AFB. There are also four more proposed RCCs which would "plug some of the holes" resulting from the network of current RCCs. The result of adding these proposed centers is a continuous umbrella of AEF coverage beginning in North America and continuing unbroken east to Midway Island in the Pacific Ocean (Dronkers, 1997).

In a briefing by Maj Ernie Eannarino from AF/XOCD (the office responsible for drafting the AEF Air Force Instruction), the AEF concept was stated as being a means to "provide regional CINCs with rapid and responsive air and space power, tailored to meet theater specific needs across the spectrum of response options from humanitarian relief to combat operations..." (Eannarino, 1997). This mention of humanitarian relief implies the flexibility of the AEF. Whereas combat AEFs would be conducted in large measure by ACC, USAFE, and PACAF (depending on location), AMC would be expected to play a the lead role in a humanitarian AEF (HAEF) (Eannarino, 1997).

Specific strengths of AEFs are defined to be speed, strength, and flexibility. AEFs are designed to be a rapid and decisive response to hostilities anywhere in the world. To allies of the United States, AEFs represent a commitment on behalf of the US to share the risks and burdens of conflict. To our adversaries, they represent "a credible and flexible deterrent" (Eannarino, 1997). In this manner, AEFs can be expected to play a major role in future conflicts, as well as in military operations other than war (MOOTW).

At the time of presentation by Major Eannarino, there had been four AEFs:

AEF I:	Oct-Dec 1995 (18 aircraft); Shaikh Isa, Bahrain
AEF II:	Apr-Jun 1996 (30 aircraft); Azraq/Hasan, Jordan
AEF III:	Jun-Aug 1996 (34 aircraft); Doha Int'l, Qatar
AEF IV:	Feb-Jun 1997 (30 aircraft); Doha Int'l, Qatar

Note that dates given for these prior AEFs imply durations longer than the time AEFs are designed to be active. The AEF phase of a deployment is intended to last seven days. During this time, the build up for the main force is under way. If the conflict continues, the main force will augment the AEF. Equipment needed for the full three- or four-month deployment of the first four AEFs may not be needed for a seven-day AEF.

Challenges associated with host nation agreements are again a concern for the Air Operations Office. This was also a concern mentioned by Captain Vaughn of AFLMA. Benefits of an AEF over traditional deployments include a reduction in "permanent and obtrusive presence" of United States forces in other countries. When the Air Force becomes capable of deploying light, the need for standing troops overseas will decrease. This would help reduce the tensions between the United States and host nations (Eannarino, 1997).

The Air Operations Office also saw the need to create an "AEF mindset" in the force. This includes changing the paradigms in training and doctrine. For AEFs to be successful and become a viable threat to potential enemies, more emphasis needs to be placed on the logistics involved with sending 1000 personnel and 36 aircraft anywhere in the world and being operational within 48 hours of the warning order. This requires a

change in the current mindset of *sending* equipment unless it *is not* needed to one of *not sending* equipment unless it *is* needed (Eannarino, 1997).

Robert S. Tripp of the RAND Corporation presented a briefing at the December 1997 Implementation Conference entitled, *Leveraging Logistics to Enhance the Effectiveness of Strike Air Expeditionary Forces*. The briefing addressed innovative methods of supporting AEFs. Under the umbrella of supportability, the issue of fuel distribution was brought to light. Currently, POL (petroleum, oil, and lubricants; here the term applies to fuel) is supplied by transporting large fuel trucks via ten C-141s. An option under consideration is to use what are termed “austere hot pits”. These are simply large underground fuel pits at the flightline of the deployed location. If these are present at the deployed location, this would be the preferred method of POL transport (Tripp, 1997).

Leasing POL trucks from host nation military or civilian contractor is another option. This requires a good relationship with the host nation, a point that was already mentioned as being essential to the success of an AEF. Finally, limiting deployments to locations with adequate POL distribution systems is the best way to ensure an uninterrupted supply of fuel, but this may run contrary to the goal of flexibility in an AEF. Securing an adequate POL distribution system in the four current RCCs already discussed goes a long way in reducing the amount of supportability needed for an AEF (Tripp, 1997).

Billeting of personnel was discussed as being essential to mission success. One current method of housing troops is called “harvest falcon housekeeping sets”. These are

large tent-like structures, but with a more rigid frame. Future options include large, prepositioned structures at the likely deployment centers. When deploying to extremely austere locations, the most likely avenue of billeting and messing would be to issue tents and meals, ready to eat (MREs) to the personnel participating in the AEF. Finally, the least flexible option is to limit deployments to areas with adequate quarters (hotels, barracks, warehouses, etc.) already in place (Tripp, 1997).

The emphasis on good military-host nation relations was implied in this briefing also. If the hosts at the proposed RCC agree to allow the United States to preposition fuel, billeting, and munitions, the deployment footprint to these locations would be drastically reduced.

Prior THUNDER Research

Another topic researched was the THUNDER simulation software package. This was of particular interest in this effort since THUNDER output would serve as the data for analysis. Captain Timothy Webb completed a study entitled, *Analysis of THUNDER Combat Simulation Model.* Sponsored by the Campaign Analysis Branch of the Aeronautical Systems Center, Captain Webb attempted to determine which input parameters affected the MOEs he chose to investigate and to what degree.

Captain Webb explains the two methods of determining the number of replications in an experiment. The first method is called fixed sample size. Using this method, the researcher simply determines the number of runs necessary to achieve the desired significance level based on statistical calculations. This method is acceptable if

the mean and variance of the parameters under study experience little change through the replications (Law and Kelton; 1991: 532).

The other method is the sequential approach. The sequential approach adds one replication at a time until the desired confidence interval of the MOE is obtained. The disadvantage of the fixed sample approach, Webb explains, is that the operator has no control over the width of the resulting confidence interval. A disadvantage associated with the sequential method is that the variance of the parameter under study may be so large that the number of runs needed to obtain the desired confidence could be prohibitively large. The analyst would not be aware of the large variance unless periodic calculations are performed (Webb, 1994: 3-1).

Captain Webb ran the predetermined number of replications in THUNDER for each scenario and used three different methods (the Bayesian approach, the Iterative approach, and Response Surface Methodology [RMS]) for determining significance of the factors under study. Each of the three methods resulted in a second order regression equation which represented the MOE under study mathematically. The regression equations were used to predict the given MOE to within 90 percent certainty. Confidence intervals for each parameter were established, a procedure which will be undertaken in this study also.

Captain Webb offers an equation from Law and Kelton which can be used to determine the number of repetitions needed to obtain a given level of confidence for the MOE under study. He also uses an equation to determine the accuracy of the models he created via stepwise regression. The term used to describe error in the models is *mean*

absolute percent error (MAPE) and is calculated for each of the three methods used to determine significance of factors in the models. Many of Captain Webb's conclusions consist of comparisons between the three methods of factor significance determination (Webb, 1994: 5-3).

Major David Davies completed a thesis entitled *Sensitivity Analysis of the THUNDER Combat Simulation Model to Command and Control Inputs Accomplished in a Parallel Environment.* Major Davies modified those input files which included command and control (C2) parameters, and compared how those modifications affected the output. Major Davies then took the additional step of studying time savings obtained by running the simulation on parallel processors.

The methodology used in this study emulates the five-step process used by Major Davies in the execution of his study. First, input variables affecting aspects under study were determined. In the case of this effort, those parameters in THUNDER determining effectiveness of air packages were manipulated (Davies, 1998: 46).

Major Davies then selected output metrics to compare between different scenarios. These included exchange ratios (number of air-to-air kills for Blue [friendly] side divided by those of the Red [enemy] side), total amount of enemy equipment destroyed, and days needed to decrease Red air strength to 10 percent of its original level, defined as air superiority. After determining output metrics, the experiment was then designed. In Major Davies' case, this included modifying the appropriate input data files and planning the simulation runs such that a minimum number or runs would be required

to obtain the desired results the first time through, without the need of additional runs at a later time (Davies, 1998: 70).

Step four included designing the parallel system in which to run the simulations necessary for his thesis. This was included as a sub-task by his thesis sponsors as a means to validate the concept of the Simulation and Analysis Facility (SIMAF) at the Aeronautical Systems Center and will not be conducted in this effort. Finally, Major Davies conducted the simulation runs, then collected, analyzed, and reported the outcomes (Davies, 1998: 73).

The output metrics chosen by Major Davies are of particular interest since they suggest useful, validated measurements that can be used in other studies. Major Davies considered five measurements of interest. The air-to-air exchange ratio, defined as Blue air-to-air kills divided by Red air-to-air kills suggests the expected relative number of kills for both sides during a protracted engagement. Surface to air exchange ratio provides insight into the vulnerability of each side's aircraft to the opposition's air defenses. This statistic can also suggest the effectiveness of air defenses for both sides (Davies, 1998: 70).

Total number of Red tanks, artillery, armored personnel carriers, trucks, and infantry vehicles destroyed indicates the effectiveness of the Blue side in attacking air-to-ground targets. Days to achieve air superiority was also examined. On the surface, this measurement would seem to lend insight into the effectiveness of the Blue forces in air-to-air combat. Looking deeper into this statistic can also reveal characteristics about the

Red forces. Early attrition to 10 percent of day one forces (the definition of air superiority) can suggest an aggressive Red force (Davies, 1998: 70).

Finally, the war on the ground as simulated by THUNDER is affected by the air war. Days to halt FLOT (forward line of operating troops, that is, the "front") movement is also a useful measure. This is defined as the number of days which elapse from the time the Blue forces begin losing ground (usually the outset of a repetition) to when they halt the Red advance and begin reclaiming ground (Davies, 1998: 70).

Lieutenant Colonel John Siegner also used THUNDER in the accomplishment of his thesis, *Analysis of Alternatives: Multivariate Considerations.* Lt Col Siegner used THUNDER as a way of comparing different weapon systems being considered for acquisition. Like Major Davies, Lt Col Seigner was also validating the SIMAF at the Aeronautical Systems Center, which proposed to run analyses of alternatives (AOAs) for proposed acquisitions. Data describing a notional aircraft, the F-XX, and a notional air-to-air missile, the AIM-XX, were input into THUNDER and compared with known data from the F-15C and the AIM-9 air intercept missile. These comparisons served as a way to determine those performance characteristics which would be sought after in new acquisitions (Siegner, 1998: 1-4).

Lt Col Siegner introduces the idea of *data mining* as a means of extracting information from large sets of raw data. Data mining by way of visualization is the most elementary method, but is only effective for small data sets with easily distinguished elements. More sophisticated software packages apply analytical tools and mathematical techniques to larger data sets to obtain desired information (Siegner, 1998: 17-19).

Linking Procurement Dollars to an Alternative Force Structures' Combat Capability Using Response Surface Methodology is the title of a thesis completed by Major James Grier that used THUNDER to simulate combat for different prospective force structures. The objective was to compare different force mixes of weapon systems in terms of combat effectiveness and total force cost. This information is useful input for the planning, programming, and budgeting system (PPBS) used by the Federal Government to determine those projects which receive federal funding and those that do not. In this manner, Major Grier used THUNDER as a means to determine the effectiveness of force packages under consideration for federal funding. Those force mixes which provide optimal combinations of combat effectiveness, cost, and other constraints can be used to influence planning during the budgeting process (Grier, 1997: 1-3).

THUNDER provided seven output parameters of interest on which Major Grier performed a stepwise regression analysis to identify those weapon systems which significantly affected overall system capability. Major Grier also performed a second-order analysis to determine interaction between variables. Systems which were found to impact output were used to build an 11-space surface (the *response surface* used in the response surface methodology). The surface was defined as the set of points resulting from all possible values of independent variables entered into the regression equation. The regression equation was used as an objective function in an integer programming (IP) problem to determine the most effective force mix given a set of constraints (Grier, 1997: 60).

Constraints included procurement dollars, operations and maintenance costs, production limitations, treaty limits, and integer values for decision variables. The solution of the resulting IP is the most effective weapon system mix of aircraft and munitions given the aforementioned constraints (Grier, 1997: 60). The thesis was evidence of THUNDER's versatility beyond simple campaign analysis. Major Grier looked "beyond the war" and analyzed the big picture of military war planning.

Logistics Research

Since this thesis deals also with the logistics involved with deploying aircraft and support equipment, past research in these areas was also of interest. *Development and Analysis of a Dual-Role Fighter Deployment Footprint Logistics Planning Equation* by Captain Stanley Griffiss and Captain Joseph Martin consisted of the development of linear regression equations for which the number of primary assigned aircraft (PAA) served as the independent variable. These regression models estimated the number of C-141 equivalents required to support the Joint Strike Fighter (JSF) for a period of thirty days (Griffis and Martin, 1996: 31).

Their research was of particular interest because it could provide an approximation for the logistics footprints of the aircraft studied in a thesis effort such as this. Griffis and Martin obtained 26 unit type codes (UTCs; documents used for logistics planning purposes) for various numbers of aircraft (primary assigned aircraft, or *PAA*) of the Block 30 F-16, Block 40 F-16, Block 50 F-16, F-15E, F-117A, and A-10. From each of the UTCs, they extracted the number of short tons of equipment needed to support the given package. They chose such a wide variety of aircraft because no deployment data

currently exists for the JSF (the JSF is scheduled for fielding in 2007) and it was expected that data would average out over all MDSs included in the study (Griffis and Martin, 1996: 45).

Logistics data for this effort were supplied by personnel in the Logistics Plans office at HQ ACC. However, the Griffis and Martin thesis could have been used in the absence of viable support data. If their work is to be used in this manner, the user should carefully examine its applicability. There are two disconnects between the work of Griffis and Martin and this thesis effort. The UTCs used in the JSF study were intended for use in a 30-day deployment. This effort concentrates on a seven day deployment, the expected length of time an AEF would be active. (If an AEF operated in a situation that was expected to exceed that amount of time, a longer deployment package consisting of a more diverse air package would be utilized.) Although exact deployment numbers specifically describing an AEF do not currently exist, a researcher could assume that the relationship between the numbers obtained by Griffis and Martin will maintain their relationship when interpolated to a seven-day deployment. That is, if the amount of equipment required to support twelve F-15Es for thirty days is 25 percent more than the amount of equipment required to support twelve Block 50 F-16s for thirty days, then the amount of equipment required to support twelve F-15Es and twelve Block 50 F-16s for seven days will hold approximately the same relationship.

The other difference between the two studies is that F-15Cs are included in this effort. Griffis and Martin did not use any F-15C UTCs in their analysis. The regression equations derived in the JSF study are "...proof of concept for modeling any future

weapon system's deployment footprint…"(Griffis and Martin, 1997: vii). Since they were created using data from existing fighter aircraft, a researcher could assume that the regression models would suggest deployment data for the F-15C with as much statistical confidence (if not more confidence, due to the fact that the input data represent current aircraft and current support methods).

Logistics data used in this analysis came from the Logistics Plans office at the AEF Battlelab and the Logistics Plans Office at Headquarters, Air Combat Command. The data consist of approximations of the number of short tons required for a given MDS. Since there have currently been no rapid response AEF deployments to date, only approximations exist for support required. The data used in this study is discussed in depth in the Findings and Analysis chapter.

III. Methodology

This chapter describes the methodology employed during the execution of this study. It begins with an explanation of THUNDER, the simulation package used to produce data on combat effectiveness which will serve as a basis of comparison between the five air packages. This chapter then describes the THUNDER input files which have a significant impact on this study. Information in these files defines the particular scenario-package combination under investigation.

These files contain information such as probability of kill (PK) data, aircraft performance and maintenance data, command and control information, satellite capabilities, and surveillance and reconnaissance data. This base scenario is copied to other files for use in future runs. Information in these files which does not remain constant includes the number and type of aircraft and enemy air defenses. These deviations from the *Storm* scenario define the particular air package and scenario used in each combination.

The section explaining the design of the experiment describes the interaction between air packages and scenarios. A description of each scenario that is used as the basis of comparison between the five packages is given in order to expose the relative strengths and weaknesses of each air package. Information such as number of enemy aircraft and surface to air threat defines each scenario and is held constant while output data from the five air packages are compiled.

For each scenario in the base case, the individual air packages are run through the simulation and the resulting output analyzed for comparison. The bases of comparison

between the five packages are termed *measures of effectiveness* (MOEs). Criteria for selecting MOEs and their significance to the study are discussed, as well as how the data were extracted from THUNDER output. The chapter then explains the procedure used to obtain the rank order of effectiveness of the air packages for each of the MOEs.

After the procedure leading to a rank order of the effectiveness for all scenario-air package combinations is reviewed, an explanation how the supportability requirement for each package is given. Data for support equipment requirements were supplied by personnel in Logistics Plans at HQ ACC. This requirement, expressed in terms of short-tons of equipment, is important to this study because it will be a limiting factor when the decision is made to deploy a force. The discussion includes the source of the numbers, assumptions which are made when using the figures, and other factors of concern to the logistics analyst.

THUNDER Input Data Files

squadron.dat - The first section of the *squadron.dat* file assigns a four-digit number to each type of aircraft in theater and defines sortie profiles. The four-digit identification assigned to each MDS is used in other files to reference a particular type of aircraft. The profiles describe the number of sorties each aircraft can fly on a given day of the war, in terms of sustained generation (*AUTH.QTY.SORT/DAY*) and a surge capability (*AC.MAX.SORT/DAY*) numbers and maximum capability (THUNDER Analyst Manual [TAM], Version 6.4, Vol 3; 11: 1996).

The second section of the file defines each individual squadron in theater. *SUP.CMD.ID* is a four-digit number assigned in the *airplan.dat* file which defines

capabilities of squadrons with a particular command identification. *TYPE.AC.ID* is the four-digit number assigned to each MDS in the first section of this file. *AUTH.QTY* defines the number of aircraft in theater from that a particular squadron. This is the number that is manipulated to represent the air packages as defined earlier. *SERV.KIT.ID* is the four-digit number assigned to the service kit for each MDS in the *acserv.dat* file (TAM, Version 6.4, Vol 3; 1996: 11).

Finally, for each squadron, the strength of that squadron in performing each mission in THUNDER is defined. These are scaled from zero (no effectiveness) to 100 (perfectly effective). These numbers are multiplied by similarly defined factors in the *typeac.dat* file to determine the squadron's effectiveness at performing a given mission. (The *typeac.dat* file defines each MDS's effectiveness, the *squadron.dat* file defines each squadron's effectiveness.) The product is used by THUNDER to determine the overall effectiveness in the routine used to assign squadrons to missions. It is in this manner that squadrons are created to perform the three missions of air-to-air, air-to-ground, and SEAD (TAM, Version 6.4, Vol 3; 1996: 11).

airmunt.dat - The *airmunt.dat* file assigns each of the munitions programmed in THUNDER a three-digit number identifying that munition in other files. The file also lists the function, weight, effective radius, and other information about each munition. The *harmpk.dat* file lists those munitions used to suppress enemy radar site by identification number as assigned in *airmunt.dat* (TAM, Version 6.4, Vol 3; 1996: 10).

harmpk.dat - The *harmpk.dat* file contains a section entitled *RADAR.KILLER.IDS.* Within this section, *BLUE..ID* lists the munition-aircraft combination for the AEF.

For the purpose of this study, the only combination listed is the Block 50 F-16 deploying the AGM-88. The AGM-88 is also known as the *H*igh-speed *A*nti*R*adiation *M*issile (*HARM*). The aircraft (Block 50 F-16) is identified by the four-digit designation assigned in the *squadron.dat* file. *harmpk.dat* uses the three-digit number used in *airmunt.dat* to identify each weapon and assigns a five-digit number to define possible HARM/aircraft combinations and their PKs (TAM, Version 6.4, Vol 3; 1996: 9).

The next section in *harmpk.dat* is entitled *HARM.SPW.VS.ENEMY.GROUND.RADAR.PKS.BY.NUM.AD.TARGETS.BAND.* This section assigns the PK for each five-digit aircraft/antiradiation missile combination against enemy air defense sites. The coordinates for enemy air defense locations are given and each assigned a four-digit number in *adcomplex.dat*. This number is how each site is referred to in *harmpk.dat* (TAM, Version 6.4, Vol 3; 1996: 9).

The PK values in *harmpk.dat* are assigned based on a function with independent variable values from zero to one. PKs are dependent variables defined at interpolated points on the function. The PK for the AGM-88 *HARM* missile is defined as 0.40 and held constant throughout all packages (TAM, Version 6.4, Vol 3; 1996: 9).

acmaint.dat - The *acmaint.dat* file defines maintenance characteristics of aircraft involved in the simulation. The maximum time for each side to return a damaged aircraft to operation is defined, as well as three degrade curves. The degrade curves produce a factor by which baseline maintenance times are multiplied based on the percentage of an airbase's maintenance capability that is available at the time an aircraft needs repair. The

file defines a degrade curve for each of three types of maintenance activities: rearm/refuel, short term repair and, long term repair (TAM, Version 6.4 Vol 3; 1996: 11).

Aircraft are differentiated by their four-digit identifier assigned in the *squadron.dat* file. Under each aircraft type, the user decides whether or not high or low resolution maintenance data are desired. High resolution takes aircraft battle damage from each possible mission profile into account and what types of damage are possible. Low resolution simply assigns an aggregate probability of short term and long term maintenance needs. Regardless, rearm and refuel time distributions are defined, as well as which of the degrade curves defined above will be used to produce the repair time multiplier (TAM, Version 6.4, Vol 3; 1996: 11).

If low resolution maintenance data are desired by the user, they are produced based on the user-defined probabilities, and repair time distributions are defined (for both short and long term maintenance performed at either the primary [main] base or a secondary [divert] base) given that an aircraft sustained battle damage (TAM, Version 6.4, Vol 3; 1996: 11).

If high resolution maintenance data are required, probabilities of sustaining battle damage are defined by the user for each of the possible mission profiles. Additionally, probabilities of sustaining various different types of battle damage (sheet metal, avionics, structures, hydraulics, etc) are defined and used to determine, for instance, the probability of requiring long term maintenance on a rudder. Repair time distributions are also defined based on whether or not the repairs are conducted at the main base or an alternate base (TAM, Version 6.4, Vol 3; 1996: 11).

typeac.dat - The *typeac.dat* file defines characteristics for each MDS in the theater. The radar cross section (RCS) is given for each aircraft, as well as the available defensive air-to-air loads. Aircraft are again identified by the four-digit numbers assigned in the *squadron.dat* file. For each aircraft, performance characteristics of seven flight profiles are defined in terms of altitude and speed. Length of runway required for take off and landing are given for various situations. The number of sorties an aircraft is capable of flying during day and night operations are given (TAM, Version 6.4, Vol 3; 1996: 10).

Mission data are also defined. This includes the minimum flight size, dimensions of combat patrol box, and the number of targets that can be attacked per sortie. Of primary concern in this effort are the configuration data. Additionally, effectiveness for each mission performed is defined in this section. These values are used along with similar values in the *squadron.dat* file to determine the effectiveness of each squadron performing a given mission. Altitude (high or low) is also defined for each mission (TAM, Version 6.4, Vol 3; 1996: 10).

The next section in the file defines fuel configurations and assigns a four-digit number to each. The configurations define capacity, amount of first and second refuels and the increase in RCS, if any. Burn profiles (rates in pounds per minute) are defined in this section for each flight profile and also assigned a four-digit number for use later in the file (TAM, Version 6.4, Vol 3; 1996: 10).

The next section of the file defines weapons configurations available for both air-to-air and air-to-ground missions. The section contains the types of ordnance carried and

the quantities of each. Fuel configuration and burn profiles are included for each configuration as defined above, as well as the increase in RCS of the aircraft/munitions combination attributable to the load. For each configuration, launches per air-to-air engagement are given, as well as the percent of available command and control with and without advanced early warning (AEW) aircraft (TAM, Version 6.4, Vol 3; 1996: 11).

Mission effectiveness for each configuration can be entered to affect the overall effectiveness as defined in the *squadron.dat* and in the aforementioned section of *typeac.dat*. Information about each type of munition is given based on the three-digit number assigned in *airmunt.dat* in terms of quantity, circular error probability (CEP), and the increase in radar configuration attributable to a particular munition. Finally, radar jamming capability is defined (TAM, Version 6.4, Vol 3; 1996: 11).

airplan.dat - The *airplan.dat* file defines the air war. For each of nineteen missions, the need for air escort is determined and the importance of escort for each mission is entered. Additionally, the need for radar jamming and SEAD is determined and importance of such support is scaled from 1 to 100 (TAM, Version 6.4, Vol 3; 1996: 15).

The file also defines characteristics of commands for use in other files and assigns each a four-digit number. Characteristics include time over target spacing in minutes and the percent of aircraft needed to continue a given mission. The primary and secondary missions for each command are defined. After assigning these attributes for each command on each side, the file takes the next step and defines which commands on each

side can perform each of the missions which THUNDER simulates (TAM, Version 6.4, Vol 3; 1996: 15).

airalloc.dat - The *airalloc.dat* file defines, for each command, the relative effectiveness of the command in performing a particular mission with respect to other missions in a particular mission class. For instance, included in the air superiority class are BARCAP (barrier combat air patrol), AIRESC (air escort), and FSWP (fighter sweep). A number representing the effectiveness of a command at performing each of these missions is assigned in the file. The effectiveness numbers assigned must sum to 100 for each mission class. The command identifiers and characteristics as defined in *airalloc.dat* are used in *squdron.dat* to further define capabilities of each squadron (TAM, Version 6.4, Vol 3; 1996: 14).

adcomplx.dat - This file simply lists air defense sites for each side. Included are location, strength, and munitions at each site (TAM, Version 6.4, Vol 3; 1996: 11).

Experiment Design

This study compares the relative combat effectiveness of five different air packages as defined by the AEF Battlelab. A second scenario was created in an attempt to find a situation which changed the rank-order of effectiveness of each package from the original *Storm* scenario. A scenario which changes the order of effectiveness results in the conclusion that effectiveness is scenario-dependent. The significance of this finding would be that war planners must consider the specific environment in which an AEF would operate and tailor the package accordingly. This includes considering the

strengths and weaknesses of each package to determine an appropriate force mix for a given situation.

The term *experiment* will be used to describe each air package-scenario combination. With five air packages and two scenarios, there will be a total of ten experiments. Each experiment will be replicated thirty times, for a total of 300 replications. Each replication will produce one data point for each of six MOEs obtained from THUNDER output, for a total of 1800 data points. MOEs to be examined are as follows:

1. Number of Blue air-to-air losses (BAAL)
2. Number of Red air-to-air losses (RAAL)
3. Number of Blue losses to Red air defenses (BSAML)
4. FLOT movement (FLOT)
5. Number of Blue air-to-ground kills (BAGK)
6. Number of unscheduled maintenance activities performed on Blue aircraft (BMX)

Scenario One - The first scenario is the original *Storm* scenario, with a reduced enemy air presence and air defense system. Original numbers of AEW control and surveillance aircraft were maintained for both sides (12 AWACS and 6 JSTARS aircraft for the AEF, and 6 Mainstay [Soviet AEW aircraft] for enemy forces). The number of B-52s in theater was also set constant at six. This research assumes that these aircraft are a "fixed cost" of conducting an air war and would be included in any package either side would send to the fight.

When only the AEF aircraft were entered into *squadron.dat* (and enemy forces left intact) in trial runs, the result was useless data; the AEF was eliminated early in the

scenario. Obviously, an AEF would not be an appropriate response for a scenario such as defined by *Storm*. This necessitated the modifications to the *Storm* scenario.

Conversely, eliminating too much of the enemy threat results in an unrealistic advantage in favor of the AEF. The end product of this force mix is also useless data. Care was taken to modify the numbers of enemy forces in such a way as to result in meaningful data. The final result was that a force consisting of 36 MiG-23s produced data that was useful. The MiG-23 is an appropriate choice of aircraft to engage because it represents a formidable opponent in both the air-to-air and air-to-ground role (according to the original *squadron.dat* and *typeac.dat* files in the *Storm* scenario). The number of MiG-23s was determined by simply equaling the number of AEF aircraft (36).

Although this fabricated enemy force produced useful data, a homogeneous enemy force structure is not realistic. To create a realistic enemy force structure, the 1998 edition of *Jane's World Air Forces* (JWAF) was consulted. According to JWAF, Iraq maintains an inventory of 60 MiG-23s, 8 MiG-29s, 60 F-1s, and 40 MiG-21s (Jackson, 1998). If there are 36 enemy aircraft in theater in the same proportion as the aircraft above, the following force mix is produced:

13 MiG-23s
2 MiG-29s
13 F-1s
8 MiG-21s

The original *adcomplx.dat* file contained forty enemy air defense sites. This number was then doubled in an effort to create the second scenario. This modification resulted in a substantial number of air defense losses for AEF aircraft. If the second

scenario was to have twice the number of air defense sites, the number must be reduced in scenario one. The number was therefore reduced to twenty to define the first scenario. It is the above mix of enemy aircraft (along with six Mainstay aircraft) and each of the five AEF packages (each AEF package also including twelve AWACS aircraft, six JSTARS aircraft, and six B-52s) which constitute the first five experiments in this study.

Scenario Two - The second scenario restores the number of enemy air defense sites to its original value of forty and decreases the number of enemy aircraft. The same process was followed to create a scenario which resulted in meaningful data as was followed to create the first scenario. With a relatively small number of aircraft originally in theater, there could be little decrease in the original number to result in output worth investigating. After experimentation, it was determined that reducing enemy aircraft by 25 percent produced consequential data. Keeping original proportions intact, this resulted in the following enemy force mix:

10 MiG-23s
1 MiG-29
10 F-1s
6 MiG-21s

This new force mix was entered into the *squadron.dat* file by inputting the appropriate number under *AUTH.QTY* for each aircraft.

Random Number Generation - The same random number stream is used throughout all experiments to determine the outcome of engagements, resulting in *correlated data.* This procedure is known as *correlated sampling.* Correlated sampling is utilized due to the fact that it "...usually reduces the variance of the estimated

difference of the performance measures and thus can provide, for a given sample size, more precise estimates of the mean difference than can independent sampling." (Banks, Carlson, and Nelson; 1996: 475). This method of testing reduces the impact of the random numbers themselves on the outcomes, and result in actual performance parameters of weapon systems having a greater impact on decisions. Any bias that the random numbers may introduce into the system is dampened by the same numbers being used in each experiment.

The version of THUNDER used in this study has ten built-in random number generating streams. Although it is impossible to assign each function its own random number seed, the ten which are available were assigned to blocks of functions. However, according to Lt Col Seigner, "...the complexity and multitude of interactions in the model contribute to the uncertainty of the variance reduction achieved through the synchronization scheme..." (Seigner, 1998: 40-41). Although the streams will still diverge within a given function, this is the advised method of using the available random number streams in attempting to reduce variance.

Rank Ordering Effectiveness

To get an idea of the rank order of effectiveness, the five air packages are run in THUNDER in the base scenario, each with thirty replications. Statistical tests are conducted on each of the output metrics to determine the effectiveness rankings. The procedure is then repeated for scenario two in an attempt to create a different rank order of the five packages. When all experiments are complete, ten tables are constructed (one

for each scenario-package combination) with a column heading for replication number and each MOE. These tables appear in Appendix A.

Bonferroni Procedure - This approach allows the analyst to control experiment-wise error when selecting the "best" package for each MOE. The definition of *best* depends on the particular MOE being examined. When comparing the packages in a scenario based on the number of Red air-to-air losses, the best is determined by that package which scores the highest. When a comparison is made based on the number of Blue air defense losses, the best is determined by that package which scores the lowest.

Since each MOE is compared with respect to five air packages, there are a total of 5(5-1)/2 = 10 comparisons which will be made for each MOE. For each comparison, a $1 - \alpha_j = 99$ percent confidence interval will be constructed, where j represents a particular comparison ($j = 1,2,\ldots 10$). S_i will be the statement that the ith comparison contains the difference being estimated. For example, S_1 could be "Number of air-to-air losses for Blue aircraft for package one minus the number of air-to-air losses for Blue aircraft for package two is contained with the interval (1.5 , 2.5)." (Banks, Carson, and Nelson; 1996: 492).

The Bonferroni inequality draws a relationship between the probability that all ten statements are true and the desired confidence as follows:

$$P(\text{all statements } S_i \text{ are true, } i = 1,2,\ldots 10) \geq 1 - \Sigma_{\text{all } j}\, \alpha_j = 1 - \alpha_e = 0.90$$

where $\alpha_e = \Sigma_{\text{all } j}\, \alpha_j = 0.10$ is the overall (experiment-wise) error probability. The Bonferroni inequality is equivalently stated as:

P(one or more statements S_i is false, i =1,2,...10) $\leq \alpha_e$, or alternately

P(one or more of the ten confidence intervals does not contain the difference being estimated) $\leq \alpha_e$ (Banks, Carson, and Nelson; 1996: 492).

The significance of these inequalities is that they hold even when the common random number sampling technique is used. This property makes the Bonferroni approach attractive for the purpose of this study as a means of comparing output of the five air packages (Banks, Carson, and Nelson; 1996: 492).

The first step in conducting a Bonferroni comparison is to define the overall error probability, α_e. For this study, $\alpha_e = 0.10$. Next, $\alpha_j = \alpha_e/10 = 0.01$ for j=1,2,...10 since there are ten comparisons for each MOE (Banks, Carson, and Nelson; 492: 1996). The thirty replications of each experiment are sufficient to assume that the values for the differences between each package for each MOE are normally distributed according to the Central Limit Theorem, but the sample variance (variance of the differences) still must be calculated to determine statistical significance (McClave and Benson, 1994: 282).

Recall that there are 10 comparisons of air packages for each MOE. The comparison between each two-package combination is based on confidence intervals for the difference between mean values of MOEs. For example, the first confidence interval to be constructed will be for the difference in Blue air-to-air losses between package one and package two in scenario one. Letting the mean of the thirty replications from package one equal θ_1 and the mean from package two equal θ_2, the confidence interval will be:

$$x \leq \theta_1 - \theta_2 \leq y$$

where x is the lower bound and y is the upper bound of the interval. If x is greater than zero (and assuming $x \leq y$), then the quantity θ_1 - θ_2 is positive within the specified confidence and therefore $\theta_1 > \theta_2$. If y is less than zero and the assumption that $x \leq y$ is maintained, the quantity θ_1 - θ_2 negative within the specified confidence and therefore $\theta_1 < \theta_2$. If x is less than zero and y is greater than zero, then no conclusions can be drawn about which of θ_1 and θ_2 is greater, and therefore no ranking will exist between the two air packages for that particular MOE (McClave and Benson, 1994: 869).

The lower bound on the interval, x, is determined by the following formula:

$$x = \mu_{D1,2} - (z\alpha_j s_{D1,2})/(n)^{0.5}$$

and the value for y, the upper bound on the confidence interval, is determined in a similar fashion:

$$y = \mu_{D1,2} + (z\alpha_j s_{D1,2})/(n)^{0.5}$$

where $\mu_{D1,2}$ is the mean of the differences θ_1 - θ_2 for all replications. The term $z\alpha_j$ is the *z-score* for a 1 - α_j = 0.99 confidence interval. The factor $s_{D1,2}$ represents the standard deviation of the differences of θ_1 - θ_2 for all replications, and n is the number of replications (McClave and Benson, 1994: 869).

Each scenario-package combination has ten confidence intervals associated with it, for a total of

$$(5(5-1)/2) X 6 X 2 = 120$$

confidence intervals. Those confidence intervals which are reported appear in Appendix B. Due the large number of confidence intervals which were constructed, only those which reveal a need for additional replications are included.

Logistics Data

Data concerning the number of short-tons required to support each package were obtained from spreadsheets and current UTCs created by the Air Force logistics plans community. Two frequently studied air packages are the *Eagle Package* and the *Falcon Package*, referred to as package one and package three respectively in this study. Equipment requirements for these packages are broken down to the unit level by item, allowing the analyst to determine, for example, how many AM32A-86Ds (power units) are needed by the Block 50 F-16 squadron. In addition to this information, a unit weight and total weight for each line item are given, allowing the researcher to determine the total weight (in short-tons) of equipment needed by each unit.

For the purpose of this study, only equipment used by aircraft support personnel (maintenance, munitions loaders, etc.) was considered in the evaluation. Equipment used by personnel in fields such as security, services, medical, and civil engineering were not included. (Such equipment would also likely be considered a "fixed cost" of a deployment and would not experience much variance from package to package).

Some support equipment assumptions are necessary, given the lack of data available for analysis. No *true* AEF has occurred to date, and therefore there are no validated historical data which can be used as basis of comparison needed for this study. The spreadsheets containing the data needed for this effort were supplied by the Logistics

Plans Office at Headquarters, Air Combat Command (ACC/LGX) and are the most viable currently available.

Another need for the support equipment assumptions mentioned above is because only four of the five aircraft included in this study are represented in the *Eagle* and *Falcon* packages. For the aircraft not included in the packages above, the Block 30 F-16, other sources must be sought to determine supportability requirements. The Griffis and Martin thesis lists validated UTCs, currently in use by the Air Force, which served as inputs for the development of the regression models used to estimate equipment requirements for the JSF. One of the UTCs listed, 3FKP10, lists support required for a deployment of 12 PAA Block 30 F-16s at 141.2 short-tons. This particular UTC is known as an *aviation UTC* and includes only those items used by aircraft support personnel.

A similar restriction was in effect when using the spreadsheets supplied by ACC/LGX. Although the data are available for four of the five aircraft used in this study, attempting to estimate the *total* support required for each package, when a sole source for all aircraft does not currently exist, would have needlessly complicated the issue. More importantly, the resulting data would experience a larger margin of error due to the nonavailability of a sole source for the information for the Block 30 F-16.

The numbers for the first four packages are based on packages currently under study by the Logistics Plans community. Package five is not currently being considered as a viable AEF option, so there are no data on which to base an approximation for required support. The Griffis and Martin thesis contains a list of several current Air

Force UTCs for various aircraft and PAAs. It is on these 18 PAA F-16 UTCs as shown in Table 1 (Griffis and Martin, 1996: 45) that an approximation for required support for package five will be based.

Table 1. Package Five Logistics Data

Squadron	Short-tons	UTC
Block 30	225.9	3FKM70
Block 40	272.4	3FKM30
Block 50	213.2	3FKAA0
Total	711.5	

The following chapter contains the data obtained from the simulation runs, as well as the results of the Bonferroni method of rank ordering each MOE. The chapter also discusses logistics data related to each package in an effort to obtain knowledge about the relative difficulty in deploying each package.

IV. Findings and Analysis

This chapter discusses the results and data analysis from each of the THUNDER replications of the two notional scenarios described in Chapter 3. It is separated by headings describing the particular MOE under investigation. The final result was a rank-order of each of the packages for each of the seven measures, where justified by the described statistical procedures.

The scenario-package combinations are referred to by a code which first defines the scenario, then the air package. In such a manner, the term S*n*P*m* defines the scenario-package combination of package m (m = 1,2,3,4,5) flying in scenario n (n = 1,2) as each were defined earlier.

After each S*n*P*m* was replicated thirty times, the data were analyzed to create tables which reflect the value of each MOE for each replication. These tables appear in Appendix A. Appendix B consists of tables reflecting comparisons between individual scenario-package combinations for those combinations which required additional replications.

Bonferroni Method of Comparison

The Statistix Analytical Software package was used to determine the rank-order of the packages via the Bonferroni procedure. This process uses the mean and variance of the differences of all two-member combinations of *treatment means* (McClave and Benson), in this case, air packages. The data in Appendix B were calculated to determine the number of additional runs needed for the procedure to be more decisive. Those combinations which were found to be inconclusive were considered for additional runs.

Additional replications were accomplished if all three of the following conditions held:

- The variance of the differences was greater than 10 percent of the mean of the differences,
- The 99 percent confidence interval contained zero, and
- If it could be shown that based on the variance of differences from the first thirty runs, zero could be excluded from the confidence interval by including less than thirty additional runs.

The significance of the 99 percent confidence interval is that this level precision is required to assure an overall confidence of 90 percent after 10 mean comparisons. Those differences described by confidence intervals which contained zero and would require more than thirty additional runs to exclude zero were considered to be too small to be distinguished by THUNDER. The limit for additional runs was placed at thirty because it served as a practical ceiling. Some comparisons would require several hundred or even thousands of additional runs to conclude that a difference exists. In such cases, the conclusion was drawn that no difference could be observed with 99 percent confidence by running the packages through THUNDER. The results for cases which called for additional runs based on the above criteria appear in Appendix B.

Rank-Order of MOEs

A review of information significant to this overall study will refamiliarize the reader with that which was being investigated. The air packages were as follows:

Package 1:	12 ea F-15C (Air-to-air) 12 ea F-15E (Air-to-ground) 12 ea Block 50 F-16 (SEAD)
Package 2:	12 ea Block 30 F-16 (Air-to-air) 12 ea F-15E (Air-to-ground) 12 ea Block 50 F-16 (SEAD)

Package 3: 12 ea F-15C (Air-to-air)
12 ea Block 40 F-16 (Air-to-ground)
12 ea Block 50 F-16 (SEAD)

Package 4: 12 ea Block 30 F-16 (Air-to-air)
12 ea Block 40 F-16 (Air-to-ground)
12 ea Block 50 F-16 (SEAD)

Package 5: 18 ea Block 30 F-16 (Air-to-air)
18 ea Block 40 F-16 (Air-to-ground)
18 ea Block 50 F-16 (SEAD)

Scenario two differs from scenario one in that scenario 2 has twice as many enemy air defense sites (40) and 25 percent fewer enemy intercept aircraft (27) as scenario one. Scenario two was created in an attempt to find a scenario in which at least two air packages had a different ranking for at least one MOE, thus permitting the conclusion that air package effectiveness is scenario-dependent.

Blue Air-to-air Losses

Table 2 below summarizes the Blue air-to-air losses data for both scenarios.

Table 2. Blue Air-to-air Losses

Scenario One							Scenario Two						
Package	Mean	Groups					Package	Mean	Groups				
S1P3	2.87	X					S2P3	1.60	X				
S1P1	2.63	X					S2P1	1.37	X				
S1P2	1.18		X				S2P2	0.73		X			
S1P5	1.02		X				S2P4	0.53		X			
S1P4	0.87		X				S2P5	0.53		X			

This measure was included because it shows how vulnerable the air package is against enemy forces in the air. Table 2 is typical of how results are presented for MOEs. The crosses in the table identify the group or groups of which a particular package is a member. The columns represent homogeneity groups. No statistical

difference exists between members of the same group, or equivalently, between packages which have crosses in the same column. In scenario one, packages one and three were determined to lose a higher number of aircraft than the other three packages, but no statistical difference exists between those two packages, as evidenced by the cross for each package being in the same column. Packages two, four, and five were in the next group with somewhat fewer losses. Because these three packages are in the same group, as indicated by the crosses for each package being in the same column, no conclusions can be drawn about the difference in losses of packages two, four, and five.

After the first thirty replications, it was determined that an additional fourteen replications would be needed for a difference between packages two and five to become evident. After running an additional thirty replications, a decrease in the absolute value of the mean and a slight (12 percent) increase in the variance of the differences occurred, but no significant statistical difference was found between packages two and five.

Scenario two also had packages one and three in the group with the most losses. Packages two, four and five made up the other group in which there was no statistical difference between means.

Red Air-to-air Losses

Red air-to-air losses (RAAL) were measured as a means of determining air superiority, since every Red air-to-air loss corresponds to a Blue air-to-air kill. Those packages which are considered strong in the air-to-air role can be expected to score high in this category. Table 3 summarizes Red air-to-air losses data between the two scenarios for all packages.

Table 3. Red Air-to-air Losses

Scenario One							Scenario Two						
Package	Mean	Groups					Package	Mean	Groups				
S1P1	1.73	X					S2P1	1.57	X				
S1P3	1.67	X					S2P3	1.50	X				
S1P5	0.10		X				S2P2	0.00		X			
S1P2	0.00		X				S2P4	0.00		X			
S1P4	0.00		X				S2P5	0.00		X			

In scenario one, packages one and three were statistically in a group by themselves with the most air-to-air kills. Packages two, four, and five made up the other group with statistically fewer air-to-air kills.

The same groupings occurred in scenario two, although the means were slightly lower for each package that experienced a Red air-to-air loss in scenario one. When these data are compared with those from Table 2 (BAAL), it is evident that, at least for the first seven days of the conflict, the loss/kill ratio for the Blue forces is not encouraging.

Blue SAM Losses

Air defense, or SAM (surface to air missile), losses for the Blue forces served as a means to determine the effect of the increased number of air defenses under scenario two and the effectiveness of the SEAD missions. The data are summarized in Table 4.

Table 4. Blue SAM Losses

Scenario One							Scenario Two						
Package	Mean	Groups					Package	Mean	Groups				
S1P2	23.40	X					S2P1	24.16	X				
S1P1	22.43	X					S1P2	22.78	X				
S1P4	16.07		X				S2P4	16.57		X			
S1P5	16.07		X				S2P5	16.57		X			
S1P3	15.10		X				S2P3	15.43		X			

In scenario one, packages two and one composed the group with the most losses. Packages four, five, and three constituted the other homogeneity group with fewer losses.

Scenario two resulted in the same groupings as scenario one. Based on the mean and standard deviation of the difference between packages one and two from the first thirty replications, it was determined that only two additional runs for those two packages would be needed to separate them into separate groups. After an additional fifteen runs however, the mean difference decreased from 2.13 to 1.38. This change resulted in an increase in the number of runs required to conclude a difference exists between packages one and two to 77.

Packages three, four, and five made up the group with fewer losses on average than packages one and two, but no difference could be found between the three packages. For all packages in both scenarios, there were considerably more Blue losses to enemy air defense sites than those from enemy aircraft. Additionally, doubling the number of air defense sites only fractionally increased the number of SAM losses.

FLOT Movement

FLOT movement is the distance in kilometers that the front line on the ground moves as a result of the war in the air. This is a vital statistic since the success of a campaign is usually based on the outcome of a ground war. Data describing the FLOT movement are shown in Table 5.

Table 5. FLOT Movement

Scenario One								Scenario Two							
Package	Mean	Groups						Package	Mean	Groups					
S1P1	-16.90	X						S2P1	-16.83	X					
S1P2	-16.93	X						S2P2	-16.83	X					
S1P3	-17.00	X						S2P3	-16.87	X					
S1P4	-17.00	X						S2P4	-16.87	X					
S1P5	-17.00	X						S2P5	-16.87	X					

The means represent cumulative movement for the duration of the seven-day period that the AEF is active. The negative values in the table imply that the Blue forces are being pushed back on the ground. We would expect negative values for the first few days of a conflict since it is not likely that an enemy would be pushed back immediately after the arrival of Blue forces in theater.

No significant statistical differences were found between the packages in either of the scenarios. This attributed to the fact that there was little variation in FLOT among each of the S*n*P*m* combinations. This resulted in few nonzero-valued differences between packages, therefore low standard deviations (the largest standard deviation among the differences of all S*n*P*m* combinations was 0.61) and means of differences between packages. However, scenario two resulted in slightly less ground loss than scenario one for all packages.

Blue Air-to-ground Kills

Blue air-to-ground kills (BAGK) measured how effectively each package impacted the enemy's ground resources. The data in Table 6 summarize BAGK results.

Table 6. Blue Air-to-ground Kills

Scenario One							Scenario Two						
Package	Mean	Groups					Package	Mean	Groups				
S1P4	1112.10	X					S2P4	1112.90	X				
S1P5	1112.10	X					S2P5	1112.90	X				
S1P2	1049.90		X				S2P2	1073.50		X			
S1P3	870.73			X			S2P3	928.70			X		
S1P1	789.73				X		S2P1	802.33				X	

In scenario one, packages four and five made up the group with the most air-to-ground kills. All other packages were in groups by themselves, indicating that this metric

was sensitive to the changing package composition. After the first thirty replications, no statistical difference was evident between packages two, four and five in scenario two. No difference was expected to be found between packages four and five since the values for each replication were identical for these two packages. However, based on the mean and standard deviation of the differences from the first thirty replications, package two was shown to be statistically different from packages four and five with only nine additional replications.

Table 6 represents the results of the additional replications. As stated above, no difference exists between packages four and five in either scenario. In descending order for both scenarios, packages two, three, and one were the sole members of the other three homogeneity groups. For all packages, there were more ground kills for the scenario with more air defenses (scenario two). This result is contrary to one possible logical expectation that there would be fewer ground kills in areas with more air defense sites.

Blue Maintenance Activities

The number of required unscheduled maintenance activities on Blue aircraft (BMX) reflects the degree of maintainability of each package, which affects combat capability. These data are shown in Table 7.

Table 7. Blue Maintenance Activities

Scenario One							Scenario Two						
Package	Mean	Groups					Package	Mean	Groups				
S1P4	4.30	X					S2P4	4.23	X				
S1P5	4.30	X					S2P5	4.23	X				
S1P1	2.83		X				S2P2	3.47	X				
S1P3	2.67		X				S2P3	3.10	X	X			
S1P2	2.60		X				S2P1	1.87		X			

In scenario one, packages four and five made up the group which required the higher number of maintenance activities. Packages one, two, and three made up the other group requiring fewer maintenance actions.

Scenario two resulted in the unusual situation of package three being a member of both groups, allowing for no conclusions to be drawn about that particular package. Package one was shown to require the fewest number of unscheduled maintenance actions of all packages. Packages two, four and five experienced the highest number of maintenance activities.

Short-tons Required

This measure gives an estimate of the amount of equipment needed to support a given package. The logistics measures required for this study were not available from THUNDER since the simulation precedes the AEF concept of small, lethal forces deployed for a short time. The data used in this study are best estimates currently available from the Logistics Plans community, since there has been no rapid response AEF deployment on which to base any logistics measures. Due to the nature of the data, only point estimates are available. Statistical procedures as previously mentioned do not apply to these data. The amount of equipment required, in short-tons, for each package appear in Table 8.

Table 8. Short-tons Required

Package	Mean	Groups					Package	Mean	Groups				
S1P5	749.10	X					S1P5	749.10	X				
S1P1	475.60		X				S1P1	475.60		X			
S1P3	431.00			X			S1P3	431.00			X		
S1P2	430.40				X		S1P2	430.40				X	
S1P4	385.80					X	S1P4	385.80					X

The figures are identical for each package for scenario one and scenario two because no significant changes in the required equipment would be made based on the scenarios as defined in this study. A factor such as climate could cause tailoring of the applicable UTC from scenario to scenario, if a deployment to location with an extreme (hot, cold, wet, dry, etc.) climate is imminent. Drastic changes in the enemy threat could perhaps prompt a UTC review before a deployment, but not on the scale as was experienced between the scenarios used in this study.

Package five was created as a notional package for this study as an attempt to perform a sensitivity analysis on package four, the other single MDS AEF. The large discrepancy between the first four packages and package five is due to the fact that since package five is not currently being considered for an AEF, there is no *lead unit* distinction for any of the squadrons included in the package. A lead unit is one which, during an AEF, supplies common support equipment for the package. The lead unit therefore is the heaviest unit during the deployment.

For packages one through four, a lead unit designation is made. The figures which are listed for these packages are the result of a lead unit having been assigned. Because package five has never deployed, there is no lead unit distinction. Therefore, the UTCs which served as the source for these data considered each squadron deploying independently of the other two, so all three are listed as being heavier than they actually would be.

The final chapter contains a summary of results in the form tabulated rank orderings for each of the MOEs investigated. Lessons learned will also be offered to help

other researchers venturing down paths similar to this study. The chapter will close with recommendations for further research into this area.

V. Conclusions

This chapter is a culmination of the results from the THUNDER runs, statistical procedures, and MOE ranking performed up to this point. A review of the research questions from Chapter 1 will be conducted and conclusions are suggested where statistical support is available. Recommendations for further research into related areas is offered, as well as advice for those who seek to use THUNDER in the future.

Before introducing results, the fact that these data were produced by an unclassified, notional THUNDER database must be re-emphasized. The ramification of using the *Storm* database is that the performance data and other figures contained therein will not reflect actual classified information. However, the database does provide the most reliable unclassified data available, and in situations where actual data are classified, *Storm* provides realistic estimates.

Research Questions

1. What are the rankings for the five AEF packages for each scenario in terms of each MOE?

For Blue air-to-air losses in both scenarios, packages one and three were shown to have more losses than two, four, and five. The interesting point here is that the single (F-16) MDS packages reported fewer losses than the dual MDS packages in both cases. The F-15C's greater ordnance capacity suggests it should have a higher survivability rate in an air-to-air engagement with the enemy. The validity of this finding should be verified by exercising the five AEF packages in actual (real-world) THUNDER scenarios.

When looking at Red air-to-air losses, packages one and three in both scenarios score the most air-to-air kills of the Red forces. Packages two, four and five had negligible scores. (Of the 180 replications of the simulation involving these six scenario-package combinations, only three Red air-to-air losses were recorded.) The fact that, based on the scenarios as defined in THUNDER for this study, those scenario-package combinations which experience the most losses also record most enemy kills lends evidence to suggest that these combinations engaged in more air-to-air encounters.

There are several possible reasons for this result. Those packages which were presumed at the outset of this research to be less combat capable could be perceived by the enemy as being no significant threat, or at least not significant enough to risk resources in an engagement.

Another possible explanation for the air-to-air results is that those packages which were perceived as more combat capable would pose a more viable threat to the enemy, and therefore the enemy would be willing to risk resources to repel the threat. Examination of the other MOEs will give a better idea of just how "combat capable" each package is and therefore the perception of the enemy of the threat each pose. If those packages which have high losses and few kills in air-to-air combat score favorably in other MOEs, a campaign analyst may accept these air-to-air results.

Packages one and two had significantly more losses to SAMs in both scenarios than packages three, four, and five. Knowing this, we should not jump to the conclusion that one package is particularly more vulnerable than another to enemy air defense systems. This could be the result of similar effects described above. A package with

poor air-to-ground performance would be less likely to attempt to penetrate enemy air defenses and attack critical ground targets, and therefore be less susceptible to SAM losses. Alternately, a package which sustains high air defense losses may also be the most aggressive. Such a package may be more capable in an air-to-ground role and consequently be more susceptible to air defense systems. As before, we must look at all measures before we make any conclusions about overall effectiveness.

No conclusions can be made about which air package allows for a quicker halt of enemy ground forces. For all packages in both scenarios, the average FLOT movement over all replications ranged from -17.00 km to -16.83 km. Differences between packages were too small for any conclusions to be justified.

The Blue air-to-ground kills measure is perhaps the most critical. It is this metric that most directly measures the impact of an air package on the enemy's ability to wage war. It is this quantity which allows war planners to justify the high losses as described earlier. The relative rankings between the packages were identical. Within each scenario, packages four and five recorded the most air-to-ground kills. In descending order packages two, three, and one rounded out this measurement.

Perhaps the most surprising result comes from this metric. The single MDS packages had the most air-to-ground kills in both scenarios. Alternately, package one, the package consisting of F-15Cs in the air to role and F-15Es in the air-to-ground role, recorded the fewest air-to-ground kills in each scenario. This result runs counter to the expectation that package one is the most effective due to the F-15E's ability to carry more

ordnance than the Block 40 F-16. As with the Blue air-to-air losses measure, this result requires verification in a real-world THUNDER scenario.

The final measure obtained from THUNDER, Blue maintenance activities, gives an idea of the supportability of each package. The fewer unscheduled maintenance activities a package requires, the more reliable the package can be said to be. This is the only MOE that differed between the two scenarios. In scenario one, packages four and five required more maintenance activities than packages one, two, and three.

The results for scenario two were not as clear-cut as those for scenario one. The only conclusion that could be drawn was that package one required fewer maintenance activities than packages two, four, and five. These results also run against common intuition. A logical assumption is that the smaller, single-engine aircraft, the F-16, would require less maintenance than the F-15, a larger, twin-engine aircraft.

The last measure investigated was short-tons of equipment required to support the deployment. Of the original four packages submitted for study by the Battlelab, these figures matched what was expected. The fifth package, the one which was created solely for the purposes of this study, will be analyzed separately due to the nature of how these logistics data were obtained, as described in the previous chapter.

The lightest package to deploy was the single-MDS package (package four). Packages two and three were the next lightest to deploy, with only 1.6 short-tons difference (an insignificant amount) between these two packages. Package one proved to be the heaviest to deploy. These findings do appear to support the assumption that the

single MDS package (package four) would be the lightest to deploy, due the ability to cross-utilize much of the support equipment that would accompany the lead unit.

We would also expect package two and three to be the next lightest, and somewhat similar to each other. This is because these packages are very similar to each other—they both consist of two F-16 squadrons and one F-15 squadron. If the F-16 squadrons share resources and the F-15 squadron deploys independently (and hence to a large degree is self-sufficient) for both packages, a large difference between the two packages should prompt questions.

Package one was expected to be the heaviest to deploy. This is because it consists of two F-15 squadrons and one F-16 squadron. There are two factors which contribute to this outcome. First, although it was discussed earlier that this package was among those which required the fewest unscheduled maintenance activities according these THUNDER scenarios, it is likely that more support equipment would be sent to a deployment involving the larger, twin-engine F-15.

The second reason package one would be considered the heaviest to deploy is that the deployed F-16 squadron would have to be self-sufficient. Although cross-utilization does exist between the F-15 and the F-16 for some parts and support equipment, it is not likely that an F-16 squadron would *plan* to deploy in this manner with an F-15 squadron. This would result in a heavier deployment for the Block 50 F-16 squadron.

It was mentioned earlier that package five would be analyzed separately due to the method used to obtain these data. This method resulted in a disproportionately high figure for equipment requirements. If this package is ever considered as a viable AEF

option, the logistics plans community should begin studying its logistics requirements and create documents similar to those used to obtain data for the other packages in this study. It is expected that this package would require somewhat more support than package four, but less than all the other packages.

2. Would increasing the number of aircraft in the lightest package increase that package's combat output?

In none of the ten the scenario-package combinations did THUNDER produce a significant difference between packages four and five. In fact, eight of the ten means were found to be *identical*. This finding supports the notion that when THUNDER is used to compare alternatives, such as in this case, results are more sensitive to changes in the percent of total force composition that a particular weapon system attains as opposed to keeping proportions constant and changing in the number of aircraft in the package.

3. Is the relative ranking of combat effectiveness of each air package constant throughout different threat scenarios?

The only MOE that lead to different conclusions about the ranking of packages between scenarios was Blue maintenance activities. In scenario one, packages four and five were found to require more unscheduled maintenance than packages one, two, and three. In scenario two, packages two, four and five were found to require more maintenance than package one. No conclusions could be drawn concerning the ranking of package three. For all other MOEs, conclusions regarding the rankings of the packages in scenario one were identical to those in scenario two.

It is presumed that varying the enemy threat to a larger degree than that which was performed in this study should result in changes to the ranking of the packages for various MOEs. The fact that the numbers of both enemy air defenses and aircraft were drastically reduced to produce scenarios which resulted in meaningful data may contribute to the similarities found between scenarios. Scaling down the enemy threat to the degree that was required in this study reduced the margin of allowable changes between scenarios. A larger enemy threat would allow for larger changes in that threat, and ultimately perhaps different rankings between scenarios. However, a threat that is large enough to modify in such a way that would result in changing the ranking of the packages between scenarios would likely be too large for an AEF as defined in the study.

Recommendations for Further Research

The difficulty in determining the required support for each package was a tremendous obstacle to overcome. There currently appears to be no central location for this information. The AEF concept has not yet evolved to the point where there is a consensus for required support for each package. The *Eagle* and *Falcon* packages (packages one and three respectively in this study) have received much attention and data for these packages are available.

However, the other packages in this study appear to be operationally feasible. Extrapolating from known data from the *Eagle* and *Falcon* packages in an attempt to "fit" data to the other packages was the only option available to this researcher. However, assumptions relating to the lead unit may not transfer from package to package. The logistics regarding packages two, four, and five are worthy of investigation.

It was mentioned earlier that the reader should keep in mind that the results from the THUNDER runs in this study were the products of an unclassified, notional database. Changing the database to one that depicts an actual threat could change the results of this study. However, the methodology and data analysis contained herein are applicable to any database that may be used. The researcher interested in continuing this work should consider running these packages through an actual (real world) scenario. Considering a deployment to another location should also be investigated. This study examined a Middle East scenario. Deployments to other locations should also be considered.

Another area of research utilizing THUNDER involves advances in weaponry. A briefing presented by the RAND Corporation discussed earlier in the literature review introduces a "small-smart" munition. With this new air-to-ground ordnance, a 250-pound bomb containing 42 pounds of a revolutionary high-explosive is expected to generate the same explosive power as the traditional Mk-84 2000-pound bomb containing 945 pounds of high-explosive. This advancement alone is expected to reduce the current need of thirty-two C-141 equivalents for munitions to four (Tripp, 1997).

A database including these munitions could be built with the desired result being to discover how lighter, equally destructive munitions affect the overall outcome. If the strike aircraft have enough suspension points to deploy more of these munitions, the air-to-ground results would be expected to increase.

Another area of research involving these munitions and THUNDER would be studying explosive power versus amount of high-explosive and estimate the actual circular error probability (CEP) of a Mk-84 equivalent bomb containing this new

explosive. This different (increased) CEP could be programmed into THUNDER while keeping all other parameters constant. If this avenue of study is explored, the number of bombs a strike aircraft could employ would be the same as before, but each bomb would be more powerful. The result in this case may be fewer required strikes to destroy hardened targets.

An interesting finding was that THUNDER output appears to be more sensitive to the *types* of aircraft as opposed to *number* of aircraft that make up a given package. Packages four and five have identical *mixes* of aircraft, and vary from each other only in the *number* of aircraft. These packages have similar output for each of the measures even though package five has 50 percent more aircraft than package four. Further research should be conducted to determine how many more aircraft need to be added to package four to obtain statistically different output. Further research should also be conducted on different packages (not necessarily those investigated herein) to see if this phenomenon is present in other force mixes.

Advice to Future THUNDER Users

A training class is offered by S3I (System Simulation Solutions, Inc; the contractor who currently maintains THUNDER) in Alexandria, Virginia to help analysts utilize THUNDER's full capabilities. This class is an invaluable asset to those who will be using THUNDER regularly. There has not been a need for students in the School of Logistics and Acquisitions Management to attend this class in the past. However, those students in the School of Engineering who will be using THUNDER do attend the

training. This class would certainly aid any student who wishes to use THUNDER, whether for a thesis or for their next assignment.

If a student uses THUNDER for a study such as this and does not attend the training class, their efforts will be greatly hampered. But before being able to even use THUNDER, the student must have knowledge of basic UNIX commands. Depending on the experience of the student, several months of trial and error may be required in order to obtain any data at all, let alone the volume required for a study such as this. Even after completing the runs and obtaining raw data, the student still must know how to process that data to produce usable information. This requires an understanding of UNIX.

If the student decides to use THUNDER, it is best to develop a network of contacts so as not to overly task one or two people. As stated before, there are several people at AFIT who have used THUNDER. But there are several external agencies that also use THUNDER. The two which were contacted the most in this effort were the Aeronautical Systems Center (ASC) and the Air Force Studies and Analysis Agency (AFSAA). S3I has employees contracted out to ASC to do analysis work. The central location for military THUNDER use is AFSAA. Specific contacts used in this effort appear in the Acknowledgements section. Throughout this study, every effort was made to deal first with active duty military personnel either at AFIT or AFSAA before talking to a contractor. Other points of contact can be established from the Acknowledgements page of other theses which utilized THUNDER.

Appendix A: Results for Each Scenario-Package Combination

Output data of each S*n*P*m* for each MOE by replication given by THUNDER.
Rep - Replication number
BAAL - Blue air-to-air losses
RAAL - Red air-to-air losses
BSAML - Blue surface to air (SAM) losses
FLOT - FLOT movement in kilometers (negative values imply FLOT is moving back, i.e. Blue forces are losing ground)
BAGK - Blue air-to-ground kills
BMX - Number of Blue unscheduled aircraft maintenance activities

Table 9. Scenario One, Package One Results

Rep #	BAAL	RAAL	BSAML	FLOT	BAGK	BMX
1	1	2	22	-17	753	2
2	3	2	24	-17	774	2
3	2	6	22	-17	752	4
4	1	1	25	-17	698	2
5	1	3	20	-17	772	2
6	2	0	21	-17	913	5
7	2	0	20	-17	760	1
8	6	1	21	-17	790	0
9	5	3	24	-16	802	4
10	1	1	22	-17	790	3
11	3	1	20	-16	710	4
12	5	0	21	-17	792	3
13	1	1	24	-17	790	2
14	2	1	23	-17	937	3
15	1	2	27	-17	850	2
16	2	4	21	-16	718	2
17	2	0	19	-17	779	5
18	3	0	27	-17	797	1
19	3	0	26	-17	753	1
20	3	3	18	-17	802	7
21	4	0	21	-17	804	2
22	3	2	20	-17	760	5
23	4	3	27	-17	822	2
24	3	5	20	-17	718	6
25	3	0	24	-17	797	2
26	2	2	22	-17	875	1
27	0	3	22	-17	894	4
28	3	1	24	-17	797	2
29	5	3	21	-17	763	2
30	3	2	25	-17	730	4

Table 10. Scenario One, Package Two Results

Rep #	BAAL	RAAL	BSAML	FLOT	BAGK	BMX
1	2	0	28	-17	939	2
2	0	0	23	-17	1148	4
3	2	0	23	-17	1140	4
4	1	0	15	-17	1252	3
5	3	0	28	-17	839	0
6	3	0	24	-17	974	1
7	1	0	23	-17	1108	6
8	1	0	27	-17	919	5
9	1	0	23	-17	980	2
10	1	0	20	-17	1051	2
11	1	0	25	-17	1050	1
12	1	0	21	-17	1036	2
13	0	0	22	-17	1139	3
14	2	0	19	-17	1112	2
15	1	0	22	-16	1232	0
16	0	0	22	-17	1016	0
17	2	0	20	-17	1137	5
18	1	0	21	-17	1175	5
19	0	0	22	-17	1112	5
20	1	0	24	-17	1151	0
21	1	0	28	-17	996	1
22	1	0	21	-17	1021	0
23	3	0	30	-17	756	3
24	0	0	25	-17	1012	4
25	0	0	25	-17	1099	4
26	1	0	22	-17	979	3
27	2	0	26	-17	889	3
28	3	0	22	-17	1085	2
29	0	0	22	-16	1126	4
30	1	0	29	-17	1025	2

Table 11. Scenario One, Package Three Results

Rep #	BAAL	RAAL	BSAML	FLOT	BAGK	BMX
1	2	1	13	-17	905	2
2	5	1	17	-17	811	4
3	2	0	17	-17	974	4
4	1	4	12	-17	1003	3
5	0	2	19	-17	910	0
6	1	0	11	-17	861	1
7	4	1	16	-17	732	6
8	3	1	17	-17	916	6
9	4	1	17	-17	818	2
10	3	2	14	-17	959	2
11	3	2	16	-17	926	1
12	0	2	21	-17	944	2
13	2	3	18	-17	860	3
14	0	4	18	-17	931	2
15	3	2	17	-17	769	0
16	4	2	7	-17	847	0
17	3	1	17	-17	689	5
18	4	1	16	-17	882	5
19	3	1	12	-17	990	5
20	5	2	14	-17	891	0
21	4	1	15	-17	829	1
22	6	1	14	-17	853	0
23	2	3	13	-17	976	3
24	4	0	11	-17	885	4
25	0	1	14	-17	926	4
26	5	1	13	-17	761	3
27	2	2	13	-17	781	3
28	6	4	13	-17	746	3
29	3	3	20	-17	842	4
30	2	1	18	-17	905	2

Table 12. Scenario One, Package Four Results

Rep #	BAAL	RAAL	BSAML	FLOT	BAGK	BMX
1	0	0	14	-17	1132	9
2	1	0	22	-17	1046	3
3	3	0	16	-17	1071	5
4	1	0	16	-17	1133	3
5	0	0	13	-17	1168	3
6	2	0	23	-17	983	3
7	0	0	18	-17	1137	3
8	2	0	18	-17	1116	6
9	0	0	16	-17	1127	7
10	1	0	16	-17	1114	5
11	1	0	10	-17	1114	4
12	0	0	16	-17	1216	4
13	1	0	21	-17	1068	4
14	0	0	19	-17	1140	3
15	1	0	14	-17	1127	1
16	1	0	12	-17	1096	5
17	0	0	15	-17	1144	4
18	2	0	12	-17	1081	10
19	0	0	21	-17	1131	1
20	2	0	17	-17	1057	3
21	0	0	18	-17	1100	5
22	1	0	19	-17	1103	3
23	0	0	16	-17	1170	4
24	0	0	13	-17	1164	1
25	0	0	13	-17	1183	2
26	2	0	19	-17	1034	4
27	2	0	16	-17	1080	6
28	1	0	15	-17	1089	6
29	1	0	10	-17	1130	6
30	1	0	14	-17	1108	6

Table 13. Scenario One, Package Five Results

Rep #	BAAL	RAAL	BSAML	FLOT	BAGK	BMX
1	0	0	14	-17	1132	9
2	1	0	22	-17	1046	3
3	3	0	16	-17	1071	5
4	1	0	16	-17	1133	3
5	0	0	13	-17	1168	3
6	2	0	23	-17	983	3
7	0	0	18	-17	1137	3
8	0	2	18	-17	1116	6
9	0	0	16	-17	1127	7
10	1	0	16	-17	1114	5
11	1	0	10	-17	1114	4
12	0	0	16	-17	1216	4
13	0	1	21	-17	1068	4
14	0	0	19	-17	1140	3
15	1	0	14	-17	1127	1
16	1	0	12	-17	1096	5
17	0	0	15	-17	1144	4
18	2	0	12	-17	1081	10
19	0	0	21	-17	1131	1
20	2	0	17	-17	1057	3
21	0	0	18	-17	1100	5
22	1	0	19	-17	1103	3
23	0	0	16	-17	1170	4
24	0	0	13	-17	1164	1
25	0	0	13	-17	1183	2
26	2	0	19	-17	1034	4
27	2	0	16	-17	1080	6
28	1	0	15	-17	1089	6
29	1	0	10	-17	1130	6
30	1	0	14	-17	1108	6

Table 14. Scenario Two, Package One Results

Rep #	BAAL	RAAL	BSAMK	FLOT	BAGK	BMX
1	1	0	32	-17	742	1
2	1	1	22	-17	813	0
3	1	2	24	-16	731	2
4	3	1	25	-17	740	0
5	1	5	24	-17	658	0
6	0	3	29	-17	820	1
7	1	2	21	-17	853	4
8	2	0	24	-17	853	1
9	1	0	23	-17	864	3
10	1	2	26	-16	804	0
11	2	2	23	-17	791	2
12	1	3	21	-17	843	5
13	1	2	24	-17	790	3
14	1	0	25	-17	820	3
15	1	2	30	-17	774	4
16	2	3	28	-17	838	0
17	2	0	19	-17	791	0
18	1	1	29	-17	791	1
19	3	1	24	-17	738	3
20	0	2	19	-17	892	3
21	2	1	23	-16	711	2
22	1	1	27	-17	919	5
23	2	3	24	-17	805	2
24	1	0	23	-17	828	2
25	1	5	27	-17	874	0
26	0	0	25	-16	814	2
27	1	2	25	-17	778	2
28	4	0	20	-16	846	4
29	1	1	22	-17	844	0
30	2	2	23	-17	705	1

Table 15. Scenario Two, Package Two Results

Rep #	BAAL	RAAL	BSAML	FLOT	BAGK	BMX
1	0	0	17	-17	1210	6
2	1	0	21	-17	1118	4
3	1	0	20	-17	1054	5
4	0	0	23	-17	1136	3
5	1	0	19	-16	1125	6
6	2	0	23	-17	1085	5
7	0	0	20	-17	1074	3
8	1	0	23	-17	1029	1
9	1	0	30	-17	933	3
10	1	0	25	-17	1091	1
11	0	0	21	-16	1104	10
12	1	0	18	-17	1122	3
13	0	0	24	-17	1032	2
14	2	0	27	-17	943	2
15	0	0	31	-17	1108	2
16	1	0	22	-17	1099	7
17	1	0	23	-17	1018	6
18	1	0	17	-17	1122	2
19	1	0	24	-16	1144	7
20	0	0	20	-17	1182	3
21	2	0	20	-17	1069	1
22	0	0	19	-17	1077	1
23	0	0	19	-16	1110	5
24	0	0	23	-17	1053	2
25	2	0	22	-17	1020	3
26	0	0	23	-17	1085	1
27	0	0	22	-17	1070	3
28	1	0	21	-17	1094	2
29	2	0	29	-17	940	3
30	0	0	21	-16	1183	2

Table 16. Scenario Two, Package Three Results

Rep #	BAAL	RAAL	BSAMK	FLOT	BAGK	BMX
1	1	1	15	-17	1004	3
2	0	2	15	-17	935	4
3	2	2	15	-17	911	5
4	1	4	17	-17	951	1
5	1	2	18	-17	852	2
6	4	1	18	-17	866	3
7	1	0	13	-17	936	3
8	0	1	12	-17	980	4
9	1	4	13	-17	967	3
10	0	4	17	-16	921	2
11	3	0	12	-17	958	4
12	2	3	21	-17	876	2
13	1	1	16	-17	923	3
14	2	0	9	-16	1031	1
15	1	1	15	-17	900	4
16	1	1	12	-17	1018	7
17	0	1	21	-17	945	4
18	3	2	18	-17	910	1
19	0	1	15	-17	941	1
20	2	3	13	-17	976	4
21	3	0	13	-17	844	3
22	2	2	13	-17	962	2
23	1	0	14	-17	990	4
24	2	0	18	-17	876	3
25	0	1	17	-17	992	5
26	2	2	19	-17	906	1
27	4	2	13	-17	972	7
28	1	1	15	-15	912	4
29	4	2	21	-17	849	0
30	3	1	15	-17	757	3

Table 17. Scenario Two, Package Four Results

Rep #	BAAL	RAAL	BSAMK	FLOT	BAGK	BMX
1	0	0	15	-17	1165	4
2	0	0	17	-16	1123	2
3	0	0	13	-17	1125	6
4	0	0	18	-17	1131	5
5	0	0	27	-17	1035	2
6	3	0	10	-16	1065	7
7	0	0	18	-17	1174	3
8	0	0	14	-17	1165	5
9	0	0	25	-17	1049	0
10	1	0	18	-17	1080	2
11	1	0	15	-17	1152	3
12	1	0	18	-17	1093	4
13	0	0	14	-17	1137	6
14	0	0	14	-17	1158	7
15	1	0	14	-17	1114	1
16	1	0	19	-17	1075	6
17	1	0	11	-17	1107	3
18	0	0	15	-17	1176	4
19	0	0	13	-17	1184	4
20	1	0	20	-17	1037	4
21	1	0	14	-17	1176	1
22	0	0	18	-17	1103	7
23	0	0	19	-17	1167	5
24	0	0	20	-17	1094	6
25	1	0	19	-16	1064	5
26	1	0	9	-17	1149	5
27	1	0	20	-16	1069	7
28	0	0	20	-17	1107	4
29	1	0	14	-17	1197	2
30	1	0	16	-17	1049	7

Table 18. Scenario Two, Package Five Results

Rep #	BAAL	RAAL	BSAML	FLOT	BAGK	BMX
1	0	0	15	-17	1165	4
2	0	0	17	-16	1123	2
3	0	0	13	-17	1125	6
4	0	0	18	-17	1131	5
5	0	0	27	-17	1035	2
6	3	0	10	-16	1065	7
7	0	0	18	-17	1174	3
8	0	0	14	-17	1165	5
9	0	0	25	-17	1049	0
10	1	0	18	-17	1080	2
11	1	0	15	-17	1152	3
12	1	0	18	-17	1093	4
13	0	0	14	-17	1137	6
14	0	0	14	-17	1158	7
15	1	0	14	-17	1114	1
16	1	0	19	-17	1075	6
17	1	0	11	-17	1107	3
18	0	0	15	-17	1176	4
19	0	0	13	-17	1184	4
20	1	0	20	-17	1037	4
21	1	0	14	-17	1176	1
22	0	0	18	-17	1103	7
23	0	0	19	-17	1167	5
24	0	0	20	-17	1094	6
25	1	0	19	-16	1064	5
26	1	0	9	-17	1149	5
27	1	0	20	-16	1069	7
28	0	0	20	-17	1107	4
29	1	0	14	-17	1197	2
30	1	0	16	-17	1049	7

Appendix B: Summary of Additional Replications

Table 19. Blue Air-to-Air Losses, Packages Two and Five in Scenario One

	BAAL		
Rep	S1P2	S1P5	Diff
1	2	1	1
2	0	0	0
3	2	0	2
4	1	0	1
5	3	0	3
6	3	0	3
7	1	0	1
8	1	1	0
9	1	1	0
10	1	0	1
11	1	0	1
12	1	1	0
13	0	2	-2
14	2	1	1
15	1	0	1
16	0	1	-1
17	2	1	1
18	1	1	0
19	0	1	-1
20	1	0	1
21	1	1	0
22	1	1	0
23	3	1	2
24	0	0	0
25	0	0	0
26	1	0	1
27	2	3	-1
28	3	3	0
29	0	2	-2
30	1	0	1
		Mean (1-30):	0.467
		SD (1-30):	1.196
		LLCI:	-0.1
		ULCI:	1.029
		Contains 0?	YES
		Required n:	44
		Additional reps?	YES

	BAAL		
Rep	S1P2	S1P5	Diff
31	1	0	1
32	1	0	1
33	0	3	-3
34	2	1	1
35	1	1	0
36	2	0	2
37	3	2	1
38	0	1	-1
39	2	1	1
40	1	3	-2
41	2	2	0
42	1	4	-3
43	1	2	-1
44	0	1	-1
45	3	1	2
46	1	1	0
47	2	2	0
48	0	2	-2
49	0	0	0
50	2	1	1
51	2	1	1
52	0	0	0
53	0	2	-2
54	0	1	-1
55	0	1	-1
56	1	1	0
57	3	1	2
58	3	1	2
59	0	1	-1
60	1	2	-1
		Mean (1-60):	0.167
		SD (1-60):	1.343
		LLCI:	-0.28
		ULCI:	0.613
		Contains 0?	YES
		Required n:	431
		Additional reps?	NO

Table 20. Blue SAM Losses,
Packages One and Two in Scenario Two

	BSAML		
Rep	S2P1	SP2	Diff
1	32	17	15
2	22	21	1
3	24	20	4
4	25	23	2
5	24	19	5
6	29	23	6
7	21	20	1
8	24	23	1
9	23	30	-7
10	26	25	1
11	23	21	2
12	21	18	3
13	24	24	0
14	25	27	-2
15	30	31	-1
16	28	22	6
17	19	23	-4
18	29	17	12
19	24	24	0
20	19	20	-1
21	23	20	3
22	27	19	8
23	24	19	5
24	23	23	0
25	27	22	5
26	25	23	2
27	25	22	3
28	20	21	-1
29	22	29	-7
30	23	21	2
		Mean (1-30):	2.133
		SD (1-30):	4.652
		LLCI:	2.133
		ULCI:	2.133
		Contains 0?	NO
		Required n:	30
		Additional Reps?	NO

	BSAML		
Rep	S2P1	S2P2	Diff
31	28	20	8
32	25	22	3
33	24	23	1
34	24	22	2
35	22	26	-4
36	25	26	-1
37	21	28	-7
38	25	29	-4
39	19	15	4
40	23	20	3
41	28	22	6
42	23	23	0
43	23	26	-3
44	22	29	-7
45	24	27	-3
		Mean (1-45):	1.378
		SD (1-45):	4.687
		LLCI:	-0.42
		ULCI:	3.177
		Contains 0?	YES
		Required n:	77
		Additional reps?	NO

Table 21. Blue Air-to-ground Kills, Packages Two and Four in Scenario Two

	BAGK		
Rep	S2P2	S2P4	Diff
1	1210	1165	45
2	1118	1123	-5
3	1054	1125	-71
4	1136	1131	5
5	1125	1035	90
6	1085	1065	20
7	1074	1174	-100
8	1029	1165	-136
9	933	1049	-116
10	1091	1080	11
11	1104	1152	-48
12	1122	1093	29
13	1032	1137	-105
14	943	1158	-215
15	1108	1114	-6
16	1099	1075	24
17	1018	1107	-89
18	1122	1176	-54
19	1144	1184	-40
20	1182	1037	145
21	1069	1176	-107
22	1077	1103	-26
23	1110	1167	-57
24	1053	1094	-41
25	1020	1064	-44
26	1085	1149	-64
27	1070	1069	1
28	1094	1107	-13
29	940	1197	-257
30	1183	1049	134
		Mean (1-30):	-36.3
		SD (1-30):	87.06
		LLCI:	-77.3
		ULCI:	4.597
		Contains 0?	YES
		Required n:	39
		Additional Reps?	YES

	BAGK		
Rep	S2P2	S2P4	Diff
31	1150	1076	74
32	1062	1162	-100
33	1128	1052	76
34	1099	1160	-61
35	1074	1213	-139
36	996	1170	-174
37	960	988	-28
38	1039	1146	-107
39	1175	1055	120
40	1226	1026	200
41	972	1099	-127
42	1095	1117	-22
43	964	1174	-210
44	892	1005	-113
45	1044	1117	-73
		Mean (1-45):	-39.4
		SD (1-45):	96.47
		LLCI:	-76.5
		ULCI:	-2.39
		Contains 0?	NO
		Required n:	45
		Additional Reps?	NO

Table 22. Blue Air-to-ground Kills, Packages Two and Five in Scenario Two

	BAGK		
Rep	S2P2	S2P5	Diff
1	1210	1165	45
2	1118	1123	-5
3	1054	1125	-71
4	1136	1131	5
5	1125	1035	90
6	1085	1065	20
7	1074	1174	-100
8	1029	1165	-136
9	933	1049	-116
10	1091	1080	11
11	1104	1152	-48
12	1122	1093	29
13	1032	1137	-105
14	943	1158	-215
15	1108	1114	-6
16	1099	1075	24
17	1018	1107	-89
18	1122	1176	-54
19	1144	1184	-40
20	1182	1037	145
21	1069	1176	-107
22	1077	1103	-26
23	1110	1167	-57
24	1053	1094	-41
25	1020	1064	-44
26	1085	1149	-64
27	1070	1069	1
28	1094	1107	-13
29	940	1197	-257
30	1183	1049	134
		Mean (1-30):	-36.3
		SD (1-30):	87.06
		LLCI:	-77.3
		ULCI:	4.597
		Contains 0?	YES
		Required n:	39
		Additional Reps?	YES

	BAGK		
Rep	S2P2	S2P5	Diff
31	1150	1076	74
32	1062	1162	-100
33	1128	1052	76
34	1099	1160	-61
35	1074	1213	-139
36	996	1170	-174
37	960	988	-28
38	1039	1146	-107
39	1175	1055	120
40	1226	1026	200
41	972	1099	-127
42	1095	1117	-22
43	964	1174	-210
44	892	1005	-113
45	1044	1117	-73
		Mean (1-30):	-39.4
		SD (1-30):	96.47
		LLCI:	-76.5
		ULCI:	-2.39
		Contains 0?	NO
		Required n:	45
		Additional Reps?	NO

Bibliography

Air Force Studies and Analysis Agency. THUNDER Analyst Manual Version 6.5. Arlington VA: S3I, 1996.

Banks, Jerry, John S. Carson II, and Barry L. Nelson. Discrete-Event System Simulation. Upper Saddle River NJ: Prentice Hall, 1996.

Davies, Maj David A. Sensitivity Analysis of the THUNDER Combat Simulation Model to Command and Control Inputs Accomplished in a Parallel Environment. MS thesis, AFIT/GOA/ENS/98M-02. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1998 (AD-A342703).

Dronkers, Lt Col Tony. Agile Combat Support: Enabling the RAEF Vision, Briefing presented at Mountain Home AFB ID, 13 December 97.

Eannarino, Maj Ernie. Air Expeditionary Forces. Briefing, 1997.

Grier, Maj James B. Linking Procurement Dollars to an Alternative Force Structure's Combat Capability Using Response Surface Methodology. MS thesis, AFIT/GOA/ENS/97M-07. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1997 (AD-A324058).

Griffis, Capt Stanley E. and Capt Joseph D. Martin. Development and Analysis of a Dual-Role Fighter Deployment Footprint Logistics Planning Equation. MS thesis, AFIT/GLM/LAL/96S-4. School of Logistics and Acquisitions Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1996 (AD-A319491).

Hoxie, Maj Hal, 1FW/XP, Langley AFB VA. Air Expeditionary Force Planning After Action Report. First Fighter Wing Logistics Plans Office, 1997.

Jackson, Paul. Jane's World Air Forces: Order of Battle and Inventories. Alexandria VA: Jane's Information Group, Inc., 1998.

Katzaman, SMSgt Jim. "Air Force Readies Itself for the 21st Century", Air Force News Service. August 6, 1998.

Law, Averill and W. David Kelton. Simulation Modeling and Analysis (Second Edition). New York: McGraw-Hill, 1991.

Looney, Col William, III. "The Air Expeditionary Force: Taking the Air Force into the Twenty-First Century," Airpower Journal. 4-9 (Winter 1996).

Mattson, SrA Elaine. *Commander Dedicates Battlelab, Reflects on AEF Concept*, Air Force News Service. September 11, 1997.

McClave, James T. and P. George Benson. Statistics for Business and Economics (Sixth Edition). Englewood Cliffs NJ: Prentice Hall, 1994.

Meserve, Capt Jeffery P., AEF Battlelab, Mountain Home AFB ID. Telephone Interview, 15 January 1998.

Parsons, SMSgt Steve, AEF Battlelab, Mountain Home AFB ID. Telephone Interview, 19 August 1998.

Siegner, Lt Col John J. Analysis of Alternatives: Multivariate Considerations. MS thesis AFIT/GOA/ENS/98M-07. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB OH, March 1998 (AD-A342116).

Tirpac, John A. "B-1s for Theater War", Air Force Magazine. 26-31 (June 1998).

Tripp, Robert S. Leveraging Logistics to Enhance the Effectiveness of Strike Air Expeditionary Forces. Briefing to AF/XO and AF/IL. RAND Corporation, Santa Monica CA, December 1997.

Vaughn, Capt Robert, Air Force Logistics Management Agency, Maxwell AFB AL, Gunter Annex. AEFs I-III. Briefing presented to AF/XO and AF/IL. July 1997.

Vo, 1st Lt Tam T. Exploratory Analysis of the Deployment Feasibility of United States Air Force Air Expeditionary Forces. MS thesis AFIT/GLM/LAL/97S-8. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1997 (AD-B230006).

Webb, Capt Timothy S. Analysis of THUNDER Combat Simulation Model. MS thesis, AFIT/GOR/ENS/94M-18. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB OH, March 1994 (AD-A278674).

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13. ABSTRACT (*Maximum 200 Words*)
There are currently only two force packages under consideration for Air Expeditionary Force (AEF) deployment: the *Eagle* package and the *Falcon* package. This thesis examines these and three other force packages for operational feasibility.

The comparisons made between the five packages were based on five operational measures and two which describe the logistics involved with deploying each package. The operational measures and one logistics measure are obtained from the THUNDER simulation software package. The other logistics measure, amount of short-tons of cargo required to support each package, was obtained from the Logistics Plans office at HQ ACC.

The principal contribution is a methodology for modeling and analyzing AEF packages using THUNDER and statistical tools. A key result (based on two notional scenarios) was that adding additional F-16 aircraft to the single MDS (all F-16) package had a negligible impact on many of the measures.

Furthermore, the single MDS package recorded the most air-to-air kills and enemy ground targets destroyed. These are counterintuitive, because two of the other packages contained equal numbers of F-15Cs and F-15Es. Note that these results should be verified by using an actual theater scenario for THUNDER.

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